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Summarized

PROCEEDINGS

OF

THE AMERICAN ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE.

FOR THE FORTIETH MEETING,

HELD AT

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Mr. Alexander G. McAdie, Weather Bureau.

Joseph K. McCammon, Esq.
Col. Marshall McDonald, U. S. Commissioner of Fish and Fisheries.
Mr. W J McGee, Geological Survey.
Capt. F. V. McNair, U. S. Navy, Superintendent Naval Observatory.
Mr. H. B. F. Macfarland, The Philadelphia Record and Boston Herald.
Prof. O. T. Mason, Curator of Ethnology National Museum.
Dr. T. C. Mendenhall, Superintendent Coast and Geodetic Survey.
Prof. Simon Newcomb, U. S. Navy, Supt. Nautical Almanac.
Mr. H. G. Ogden, Assistant, Coast and Geodetic Survey.
Maj. J. W. Powell, Director U. S. Geological Survey.
Prof. W. B. Powell, Superintendent of Public Schools, D. C.
Rev. J. Havens Richards, S. J., President Georgetown University.
Prof. C. V. Riley, Entomologist, Department of Agriculture.
Mr. Charles A. Schott, Assistant, Coast and Geodetic Survey.
Prof. W. H. Seaman, Patent Office.
Rev. George M. Searle, Director of Observatory, Catholic University of America.
Col. F. A. Seely, Examiner Patent Office.
Hon. W. E. Simonds, U. S. Com. of Patents.
Mr. F. W. True, Curator of Mammals, National Museum.
Dr. J. C. Welling, President Columbian University.
Col. Smith A. Whitfield, First Assistant Postmaster-General.
Prof. H. W. Wiley, Chemist, Department of Agriculture.
Mr. Bailey Willis, Geological Survey.
Mr. Thomas Wilson, Curator Prehistoric Anthrop., National Museum.
Mr. W. C. Winlock, Smithsonian Institution.

LADIES' RECEPTION COMMITTEE.

Miss ALICE C. FLETCHER, *Chairman.*

Mrs. Frances M. Abbe, Mrs. Anna R. Edes, Mrs. Anita Newcomb McGee,
Mrs. Anna Howes Barus, Mrs. Martha R. Hampson, Miss Sarah A. Scull,
Mrs. Mary S. Bigelow, Mrs. Justina Robinson Hill, Mrs. Marianna P. Seaman,
Mrs. Eliza Nelson Blair. Dr. Clara Bliss Hinds, Miss Annie Tolman Smith,
Mrs. Lucia Eames Blount, Mrs. Jean M. Lander, Mrs. Ellen Powell Thompson,
Miss Ellen W. Cathcart, Miss Emily Mason, Mrs. Jane J. Willits,
Mrs. Margaret Magnon York.

NOTE.—This Committee is composed of members of the Women's Anthropological Society of America.

COMMITTEE ON FINANCE.

GARDINER G. HUBBARD, *Chairman.*

A. T. Britton, W. A. DeCaindry, P. B. Pierce,
T. M. Chatard, L. O. Howard, B. H. Warner.

COMMITTEE ON PRINTING.

RICHARD RATHBUN, *Chairman.*

W J McGee, Dr. C. Hart Merriam.

COMMITTEE ON EXCURSIONS.

EVERETT HAYDEN, *Chairman.*

J. Stanley Brown, Bailey Willis.

COMMITTEE ON RAILROADS.

HENRY GANNETT, *Chairman.*

Everett Hayden, H. M. Wilson.

COMMITTEE ON HOTELS.

Prof. F. W. CLARKE, *Chairman.*

Dr. David T. Day, Prof. Wm. Harkness.

SPECIAL COMMITTEES OF THE ASSOCIATION.[1]

1. *Committee on Indexing Chemical Literature.*

H. CARRINGTON BOLTON of New York,
F. W. CLARKE of Washington,
A. R. LEEDS of Hoboken,
A. A. JULIEN of New York,
J.W. LANGLEY of Pittsburgh,
A. B. PRESCOTT of Ann Arbor.

ALFRED TUCKERMAN of Newport.

2. *Committee to apply to Congress for a Reduction of the Tariff on Scientific Books and Apparatus.*

E. D. COPE of Philadelphia, | J. R. EASTMAN of Washington,
S. A. FORBES of Champaign.

3. *Committee to memorialize Congress to take steps for the Preservation of Archæologic Monuments on the public lands.*

MISS ALICE C. FLETCHER of Cambridge, | MRS. M. E. STEVENSON of Washington.

4. *Committee on Water Analysis.*

G. C. CALDWELL of Ithaca,
J. A. MYERS of Agricultural Coll., Miss.,
R. B. WARDER of Washington,
J. W. LANGLEY of Ann Arbor,
W. P. MASON of Troy,
W. H. SEAMAN of Washington.

5. *Committee on the Maintenance of Timberlands and on the Development of the Natural Resources of the Country.*

T. C. MENDENHALL of Washington,
E. W. HILGARD of Berkeley,
C. E. BESSEY of Lincoln,
B. E. FERNOW of Washington,
WILLIAM SAUNDERS of Ottawa.

6. *Honorary Agent of Transportation to act with the Local Committees.*

HENRY GANNETT of Washington.

7. *Committee to secure an American Table at the International Marine Biological Station at Naples, Italy.*

C. W. STILES of Washington,
THEOBALD SMITH of Washington,
THEODORE GILL of Washington,
B. C. FERNOW of Washington.

[1] All Committees are expected to present their reports to the COUNCIL not later than the fourth day of the meeting. Committees sending their reports to the Permanent Secretary one month before a meeting can have them printed for use at the meeting.

8. *Committee on Biological Nomenclature.*

GEORGE L. GOODALE of Cambridge,
J. M. COULTER of Crawfordsville,
C. S. MINOT of Boston,
THEODORE GILL of Washington,
S. H. GAGE of Ithaca.

9. *Committee on Data for the Determination of the Secular and Periodic Changes in Terrestrial Latitude.*

T. C. MENDENHALL of Washington,
B. A. GOULD of Cambridge,
T. C. CHAMBERLIN of Madison,
R. S. WOODWARD of Washington,
F. V. MCNAIR of U. S. Navy,
G. C. COMSTOCK of Madison,
C. L. DOOLITTLE of South Bethlehem.

10. *Committee on Standards for Astronomical and Physical Units.*

S. P. LANGLEY of Washington,
E. C. PICKERING of Cambridge,
T. C. MENDENHALL of Washington,
W. R. WARNER of Cleveland,
G. N. SAEGMULLER of Washington,
WILLIAM HARKNESS of Washington,
J. A. BRASHEAR of Pittsburg,
ALVIN G. CLARK of Cambridge.

11. *Committee on the Endowment of Research Fund.*

JOHN A. BRASHEAR of Pittsburgh, Section A, *Chairman.*
FRANCIS E. NIPHER of St. Louis, " B
S. A. LATTIMORE of Rochester, " C
R. H. THURSTON of Ithaca, " D
JOHN J. STEVENSON of New York, " E
C. V. RILEY of Washington, " F
THOMAS WILSON of Washington, " H
EDMUND J. JAMES of Philadelphia, " I

12. *Auditors.*

HENRY WHEATLAND of Salem,
THOMAS MEEHAN of Germantown.

OFFICERS ELECTED

FOR THE

ROCHESTER MEETING.

AUGUST, 1892.

PRESIDENT.

JOSEPH LECONTE, Berkeley, California.

VICE-PRESIDENTS.

A. Mathematics and Astronomy—J. R. EASTMAN, Washington, D. C.
B. Physics—B. F. THOMAS, Columbus, Ohio.
C. Chemistry—ALFRED SPRINGER, Cincinnati, Ohio.
D. Mechanical Science and Engineering—JOHN B. JOHNSON, St. Louis, Mo.
E. Geology and Geography—H. S. WILLIAMS, Ithaca, N. Y.
F. Biology—S. H. GAGE, Ithaca, N. Y.
H. Anthropology—W. H. Holmes, Washington, D. C.
I. Economic Science and Statistics—S. DANA HORTON, Pomeroy, Ohio.

PERMANENT SECRETARY.

F. W. PUTNAM, Cambridge (office Salem), Mass.

GENERAL SECRETARY.

AMOS W. BUTLER, Brookville, Ind.

SECRETARY OF THE COUNCIL.

T. H. NORTON, Cincinnati, Ohio.

SECRETARIES OF THE SECTIONS.

A. Mathematics and Astronomy—WINSLOW UPTON, Providence, R. I.
B. Physics—BROWN AYRES, New Orleans, La.
C. Chemistry—J. L. HOWE, Louisville, Ky.
D. Mechanical Science and Engineering—OLIN H. LANDRETH, Nashville, Tenn.
E. Geology and Geography—R. D. SALISBURY, Madison, Wis.
F. Biology—BYRON D. HALSTED, New Brunswick, N. J.
H. Anthropology—STEWART CULIN, Philadelphia, Pa.
I. Economic Science and Statistics—LESTER F. WARD, Washington, D. C.

TREASURER.

WILLIAM LILLY—Mauch Chunk, Pa.

MEETINGS AND OFFICERS OF THE AMERICAN ASSOCIATION OF GEOLOGISTS AND NATURALISTS.

MEETING.	DATE.	PLACE.	CHAIRMAN.	SECRETARY.	ASSIS'T SEC'Y.	TREASURER.
1st	April 2, 1840,	Philadelphia,	Edward Hitchcock,*	L. C. Beck,*		
2d	April 5, 1841,	Philadelphia,	Benjamin Silliman,*	L. C. Beck,*	B. Silliman, jr.,* C. B. Trego,*	
3d	April 25, 1842,	Boston,	S. G. Morton,*	C. T. Jackson,*	J. D. Whitney, M. B. Williams,*	
4th	April 26, 1843,	Albany,	Henry D. Rogers,*	B. Silliman, jr.,*		John Locke.*
5th	May 8, 1844,	Washington,	John Locke,*	B. Silliman, jr.,* O. P. Hubbard,		Douglas Houghton.*
6th	April 30, 1845,	New Haven,	Wm. B. Rogers,*	B. Silliman, jr.,* J. Lawrence Smith,*		Douglas Houghton.*
7th	Sept. 2, 1846,	New York,	C. T. Jackson,*	B. Silliman, jr.,*		E. C. Herrick.*
8th	Sept. 20, 1847,	Boston,	Wm. B. Rogers,†*	Jeffries Wyman,*		B. Silliman, jr.*

* Deceased.

† Professor ROGERS, as chairman of this last meeting, called the first meeting of the new Association to order and presided until it was fully organized by the adoption of a constitution. As he was thus the first presiding officer of the new Association, it was directed at the Hartford meeting that his name be placed at the head of the Past Presidents of the American Association for the Advancement of Science.

MEETINGS AND OFFICERS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

MEETING.	DATE.	PLACE.	PRESIDENT.	VICE-PRESIDENT.	GENERAL SECRETARY.	PERMANENT SEC'Y.	TREASURER.
1st	Sept. 20, 1848,	Philadelphia, Pa.,	W. C. Redfield,*		Walter R. Johnson,*		Jeffries Wyman.*
2d	Aug. 14, 1849,	Cambridge, Mass.,	Joseph Henry,*		E. N. Horsford, 1		A. L. Elwyn.*
3d	Mar. 12, 1850,	Charleston, S. C.,	A. D. Bache,*2		L. R. Gibbs, 3		St. J. Ravenel.* 4
4th	Aug. 19, 1850,	New Haven, Conn.,	A. D. Bache,*		E. C. Herrick,*		A. L. Elwyn.*
5th	May 5, 1851,	Cincinnati, Ohio,	A. D. Bache,*		W. B. Rogers, 5*	S. F. Baird,*	S. F. Baird.* 6
6th	Aug. 19, 1851,	Albany, N. Y.,	Louis Agassiz,*		W. B. Rogers,*	S. F. Baird,*	A. L. Elwyn.*
7th	July 28, 1853,	Cleveland, Ohio,	Benjamin Pierce,*		S. St. John,* 7	S. F. Baird*,	A. L. Elwyn.*
8th	April 26, 1854,	Washington, D. C.,	J. D. Dana,		J. Lawrence Smith,*	Joseph Lovering,*	J. L. LeConte*8
9th	Aug. 15, 1855,	Providence, R. I.,	John Torrey,*		Wolcott Gibbs,	Joseph Lovering,*	A. L. Elwyn.*
10th	Aug. 20, 1856,	Albany, N. Y.,	James Hall,		B. A. Gould,	Joseph Lovering,*	A. L. Elwyn.*
11th	Aug. 12, 1857,	Montreal, Canada,	Alexis Caswell,* 9	Alexis Caswell,*	John LeConte,	Joseph Lovering,*	A. L. Elwyn.*
12th	April 28, 1858,	Baltimore, Md.,	Alexis Caswell,* 10	John E. Holbrook,*†	W. M. Gillespie,* 11	Joseph Lovering,*	A. L. Elwyn.*
13th	Aug. 3, 1859,	Springfield, Mass.,	Stephen Alexander,*	Edward Hitchcock,*	William Chauvenet,*	Joseph Lovering,*	A. L. Elwyn.*
14th	Aug. 1, 1860,	Newport, R. I.,	Isaac Lea.*	B. A. Gould,	Joseph LeConte,	Joseph Lovering,*	A. L. Elwyn.*
15th	Aug. 15, 1866,	Buffalo, N. Y.,	F. A. P. Barnard,*	A. A. Gould,* 12	Elias Loomis, 13	Joseph Lovering,*	A. L. Elwyn.†*
16th	Aug. 21, 1867,	Burlington, Vt.,	J. S. Newberry,	Wolcott Gibbs,	C. S. Lyman,	Joseph Lovering,*	A. L. Elwyn.†*
17th	Aug. 5, 1868,	Chicago, Ill.,	B. A. Gould,	Charles Whittlesey,*	Simon Newcomb, 14	Joseph Lovering,*	A. L. Elwyn.†*
18th	Aug. 18, 1869,	Salem, Mass.,	J. W. Foster,*	O. N. Rood,	O. C. Marsh,	F. W. Putnam, 15*	A. L. Elwyn.†*
19th	Aug. 17, 1870,	Troy, N. Y.,	T. S. Hunt,* 16	T. S. Hunt,*	F. W. Putnam, 17	Joseph Lovering,*	A. L. Elwyn.†*
20th	Aug. 16, 1871,	Indianapolis, Ind.,	Asa Gray,*	G. F. Barker,	F. W. Putnam,	Joseph Lovering.*	W. S. Vaux.*
21st	Aug. 15, 1872,	Dubuque, Iowa,	J. Lawrence Smith,*	Alex. Winchell,*	E. S. Morse,	Joseph Lovering,*	W. S. Vaux.*
22d	Aug. 20, 1873,	Portland, Me.,	Joseph Lovering,*	A. H. Worthen,†*	C. A. White,	F. W. Putnam,	W. S. Vaux.*
23d	Aug. 12, 1874,	Hartford, Conn.,	J. L. LeConte,*	C. S. Lyman,*	A. C. Hamlin,	F. W. Putnam,	W. S. Vaux.†*

1. In place of Jeffries Wyman, *not present.*
2. In place of Joseph Henry, *not present.*
3. In place of E. C. Herrick, *not present.*
4. In place of A. L. Elwyn, *not present.*
5. In place of E. C. Herrick, *not present.*
6. In place of A. L. Elwyn, *not present.*
7. In place of J. D. Dana, *not present.*
8. In place of A. L. Elwyn, *not present.*
9. In place of J. W. Bailey, *deceased.*
10. In place of Jeffries Wyman, *not present.*
11. In place of Wm. Chauvenet, *not present.*
12. In place of R. W. Gibbes, *not present.*
13. In place of W. P. Trowbridge, *not present.*
14. In place of A. P. Rockwell, *called home 1st day.*
15. In place of Joseph Lovering, *in Europe.*
16. In place of Wm. Chauvenet, *too ill to be present.*
17. In place of C. F. Hartt, *in Brazil.*

* Deceased. † Not present at the meeting.

MEETINGS AND OFFICERS OF THE ASSOCIATION (*Continued*).

MEETING.	DATE.	PLACE.	PRESIDENT.	VICE PRESIDENT, SECTION A.	VICE PRESIDENT, SECTION B.	CHAIRMAN OF PERMANENT SUBSECTION OF CHEMISTRY.	CHAIRMAN OF PERMANENT SUBSECTION OF ANTHROPOLOGY.	CHAIRMAN OF PERMANENT SUBSECTION OF MICROSCOPY.	CHAIRMAN OF PERMANENT SUBSECTION OF ENTOMOLOGY.
24th	Aug. 11, 1875.	Detroit, Mich.,	J. E. Hilgard,*	H. A. Newton,	J. W. Dawson,	S. W. Johnson,	L. H. Morgan,*	———	———
25th	Aug. 23, 1876.	Buffalo, N. Y.,	W. B. Rogers,*	C. A. Young,	E. S. Morse,	G. F. Barker,	L. H. Morgan,*	R. H. Ward,	———
26th	Aug. 29,,1877.	Nashville, Tenn.,	S. Newcomb,	R. H. Thurston,[1]	O. C. Marsh,	N. T. Lupton,	Daniel Wilson,†	R. H. Ward,	———
27th	Aug. 21, 1878.	St. Louis, Mo.,	O. C. Marsh,	R. H. Thurston,	Aug. R. Grote,	F. W. Clarke,	———[2]	R. H. Ward,[3]	———
28th	Aug. 27, 1879.	Saratoga, N. Y.,	G. F. Barker,	S. P. Langley,	J. W. Powell,	F. W. Clarke,[4]	Daniel Wilson,	E. W. Morley,	———
29th	Aug. 25, 1880.	Boston, Mass.,	L. H. Morgan,*	Asaph Hall,	Alex. Agassiz,	J. M. Ordway,	J. W. Powell,	S. A. Lattimore,	———
30th	Aug. 17, 1881.	Cincinnati, Ohio,	G. J. Brush,	Wm. Harkness,[7]	E. T. Cox,[8]	G. C. Caldwell,[9]	G. Mallery,	A. B. Hervey,	J. G. Morris.

PERMANENT SECRETARY.	GENERAL SECRETARY.	SECRETARY OF SECTION A.	SECRETARY OF SECTION B.	SECRETARY OF PERMANENT SUBSECTION OF CHEMISTRY.	SECRETARY OF PERMANENT SUBSECTION OF ANTHROPOLOGY.	SECRETARY OF PERMANENT SUBSECTION OF MICROSCOPY.	SECRETARY OF PERMANENT SUBSECTION OF ENTOMOLOGY.	TREASURER.
F. W. Putnam,	S. H. Scudder,	S. P. Langley, T. C. Mendenhall,	E. S. Morse,	F. W. Clarke,	F. W. Putnam,	———	———	W. S. Vaux.*
F. W. Putnam,	T. C. Mendenhall,	A. W. Wright,	Albert H. Tuttle,	H. C. Bolton,	O. T. Mason,	E. W. Morley,	———	W. S. Vaux.*
F. W. Putnam,	Aug. R. Grote,	H. C. Bolton,	Wm. H. Dall,	P. Schweitzer,	———[2]	T. O. Summers, jr.,	———	W. S. Vaux.†*
F. W. Putnam,	H. C. Bolton,	F. E. Nipher,	George Little,	A. P. S. Stuart,	———[2]	G. J. Engelmann,	———	W. S. Vaux.†*
F. W. Putnam,	H. C. Bolton,[5]	J. K. Rees,	W. H. Dall,[6]	W. R. Nichols,*	J. G. Henderson,	A. B. Hervey,	———	W. S. Vaux.†*
F. W. Putnam,	J. K. Rees,	H. B. Mason,	C. V. Riley,	C. E. Munroe,	J. G. Henderson,	A. B. Hervey,	———	W. S. Vaux.*
F. W. Putnam,	C. V. Riley,	E. T. Tappan,[10]	Wm. Saunders,	A. Springer,[12]	J. G. Henderson,	W. H. Seaman,[11]	B. P. Mann,	W. S. Vaux.†*

[1] In the absence of E. C. Pickering.
[2] The Subsection united with Sec. B.
[3] In the absence of G. S. Blackie.
[4] In the absence of Ira Remsen.
[5] In the absence of George Little.
[6] In the absence of A. C. Wetherby.
[7] In the absence of A. M. Mayer.
[8] In the absence of George Engelmann.
[9] In the absence of W. R. Nichols.
[10] In the absence of John Trowbridge.
[11] In the absence of S. P. Sharples.
[12] In place of H. W. Wiley, called away.
* Deceased.
† Not present.

MEETINGS AND OFFICERS OF THE ASSOCIATION. (*Continued.*)

MEETING.	DATE.	PLACE.	PRESIDENT.	VICE PRESIDENTS.				
				Section A.	Section B.	Section C.	Section D.	Section E.
31st	Aug. 23, 1882.	Montreal, Can.	J. W. Dawson,	W. A. Rogers,[1]	T.C. Mendenhall,	H. B. Bolton,	W. P. Trowbridge,	E. T. Cox,
32nd	Aug. 15, 1883.	Minneapolis, M.	C. A. Young,	W. A. Rogers,	H. A. Rowland,	E. W. Morley,	De Volsen Wood,[7]	C. H. Hitchcock,
33rd	Sept. 3, 1884.	Philadelphia, Pa.	J. P. Lesley,	H. T. Eddy,	J. Trowbridge,	J. W. Langley,	R. H. Thurston,	N. H. Winchell,
34th	Aug. 26, 1885.	Ann Arbor, Mich	H. A. Newton,	W. Harkness,[15]	S. P. Langley,[16]	N. T. Lupton,[17]	J. Burkitt Webb,	Edward Orton,
35th	Aug. 18, 1886.	Buffalo, N. Y.	E. S. Morse,	J. W. Gibbs,	C. F. Brackett,	H. W. Wiley,	O Chanute,	T. C. Chamberlin,
36th	Aug. 10, 1887.	New York, N. Y.	S. P. Langley,	J. R. Eastman,[26]	W. A. Anthony,	A. B. Prescott,	E. B. Coxe,	G. K. Gilbert,

VICE PRESIDENTS.				Permanent Secretary.	General Secretary.	Assistant Gen. Secretary.	SECRETARIES OF SECTIONS.	
Section F.	Section G.	Section H.	Section I.				Section A.	Section B.
W. H. Dall,	A. H. Tuttle,	Alex. Winchell,*	E. B. Elliott,	F. W. Putnam,	Wm. Saunders,	J. R. Eastman,	H. T. Eddy,	C. S. Hastings,
W. J. Beal,	J. D. Cox,	O. T. Mason,	F. B. Hough,*	F. W. Putnam,	J. R. Eastman,	Alfred Springer,	G. W. Hough,[8]	F. E. Nipher.[9]
E. D. Cope,	T. G.Wormley,	E. S. Morse,	John Eaton,	F. W. Putnam,	Alfred Springer,	C. S. Minot.[12]	G. W. Hough,	N. D. [illegible] Hodges,
T. J.Burrill,[18]	S. H. Gage,	J. O. Dorsey,[19]	Edw. Atkinson	F. W. Putnam,	C. S. Minot,	S. G. Williams.[20]	E. W. Hyde,	B. F. Thomas,[21]
H.P.Bowditch,	———[25]	H. Hale,	J. Cummings,*	F. W. Putnam,	S. G. Williams,	W. H. Pettee,	S. C. Chandler,	H. S. Carhart,
W. G. Farlow,	———	D. G. Brinton,	H. E. Alvord,	F. W. Putnam,	W. H. Pettee,	J. C. Arthur,	H. M. Paul,	C. Leo Mees,

SECRETARIES OF THE SECTIONS.							Treasurer.
Section C.	Section D.	Section E.	Section F.	Section G.	Section H.	Section I.	
Alfred Springer,	J. B. Webb,[3]	H. S. Williams,[4]	Wm. Osler.[5]	Robt. Brown, jr.,	O. T. Mason.	F. B. Hough,[6]*	———*
J. W. Langley,[10]	J. B. Webb,[11]	A. A. Julien,	S. A. Forbes,	Carl Seiler,	G. H. Perkins,	Jos.Cummings,*	William Lilly.
H. Carmichael,[13]	J. B. Webb,	E. A. Smith,	C. E. Bessey,	R. Hitchcock,	G. H. Perkins.[14]	C. W. Smiley,	William Lilly.
F.P.Dunnington,	C. J. H. Woodbury.	G. K. Gilbert,[22]	J. A. Lintner,[23]	W. H. Walmsley,	Erm. A. Smith,*	C. W. Smiley.[24]	William Lilly.
W. McMurtrie,	William Kent,	E. W. Claypole,	J. C. Arthur,	———[25]	A. W. Butler,	H. E. Alvord.	William Lilly.
C. S. Mabery,[27]	G. M. Bond,	W. M. Davis,[28]	J. H. Comstock,	———	C. C. Abbott,[29]	W. R. Lazenby,	William Lilly.

1 In the absence of William Harkness.
2 In the absence of Daniel Wilson.
3 In the absence of C. B. Dudley.
4 In the absence of C. E. Dutton.
5 In the absence of C. S. Minot.
6 F. B. Hough was called home and J. R. Dodge acted at the close of the meeting.
7 Absent but place was not filled
8 In the absence of W. W. Johnson.
9 In the absence of C. K. Wead.
10 W. M. McMurtrie, last three days of meeting.
11 Pro tempore.
12 In the absence of E. S. Holden.
13 In the absence of R. B. Warder.
14 In the absence of W. H. Holmes.
15 In the absence of J. M. Van Vleck.
16 In place of C. F. Brackett, resigned.
17 In the absence of W. R. Nichols.
18 In the absence of B. G. Wilder.
19 In the absence of W. H. Dall.
20 In place of C. C. Abbott, not present
21 In place of A.A. Michelson, resigned.
22 In the absence of H. C. Lewis.
23 In place of C. H. Fernald, resigned
24 In the absence of J. W. Chickering.
25 Section permanently united to Section F.
26 In place of W. Ferrel, resigned.
27 Absent; R. B. Warder acted as Sec'y Pro tem.
28 In place of T. B. Comstock, absent.
29 In place of F. W. Langdon, absent.

*Deceased.

MEETINGS AND OFFICERS OF THE ASSOCIATION *(Continued)*.

MEETING.	DATE.	PLACE.	PRESIDENT.
37th.	Aug. 14, 1888.	Cleveland, Ohio.	J. W. Powell.
38th.	Aug. 26, 1889.	Toronto, Ontario.	T. C. Mendenhall.
39th.	Aug. 19, 1890.	Indianapolis, Ind.	G. L. Goodale.
40th.	Aug. 19, 1891.	Washington, D. C.	A. B. Prescott.

VICE PRESIDENTS.

SECTION A.	SECTION B.	SECTION C.	SECTION D.
Ormond Stone.	A. A. Michelson.	C. E. Munroe.	C. J. H. Woodbury
R. S. Woodward.	H. S. Carhart.	W. L. Dudley.	James E. Denton.
S. C. Chandler.	Cleveland Abbe.	R. B. Warder.	James E. Denton.
E. W. Hyde.	F E. Nipher.	R. C. Kedzie.	Thomas Gray.

SECTION E.	SECTION F.	SECTION H.	SECTION I.
George H. Cook.	C. V. Riley.	C. C. Abbott.	C. W. Smiley.
Charles A. White.	Geo. L. Goodale.	Garrick Mallery.	Charles S. Hill.
John C. Branner.	C. S. Minot.	Frank Baker.	J. Richards Dodge.
J. J. Stevenson.	J. M. Coulter.	Joseph Jastrow.	Edmund J. James.

PERMANENT SECRETARY.	GENERAL SECRETARY.	SECRETARY OF COUNCIL.	TREASURER.
F. W. Putnam.	Julius Pohlman.	C. Leo Mees.	William Lilly.
F. W. Putnam.	C. Leo Mees.	H. C. Bolton.	William Lilly.
F. W. Putnam.	H. C. Bolton.	H. W. Wiley.	William Lilly.
F. W. Putnam.	H. W. Wiley.	A. W. Butler.	William Lilly.

SECRETARIES OF SECTIONS.

SECTION A.	SECTION B.	SECTION C.	SECTION D.
C. C. Doolittle.	A. Macfarlane.	W. L. Dudley.	Arthur Beardsley.
G. C. Comstock.	E. L. Nichols.	Edward Hart.	W. B. Warner.
W. B. Beman.	E. M. Avery.	W. A. Noyes.	Thomas Gray.
F. H. Bigelow.	A. Macfarlane.	T. H. Norton.	William Kent.

SECTION E.	SECTION F.	SECTION H.	SECTION I.
John C. Branner.	B. H. Fernow.	Frank Baker.	Charles S. Hill.
John C. Branner.	A. W. Butler.	W. M. Beauchamp.	J. R. Dodge.
Samuel Calvin.	J. M. Coulter.	Joseph Jastrow.	B. E. Fernow.
W J McGee.	A. J. Cook.	W. H. Holmes.	B. E. Fernow.

MEETINGS.	PLACE.	YEAR.	MEMBERS IN ATTENDANCE.	NUMBER OF MEMBERS.
1.	Philadelphia	1848	?	461
2.	Cambridge	1849	?	540
3.	Charleston	1850	?	622
4.	New Haven	1850	?	704
5.	Cincinnati	1851	87	800
6.	Albany	1851	194	769
7.	Cleveland	1853	?	940
8.	Washington	1854	168	1004
9.	Providence	1855	166	605
10.	2nd Albany	1856	381	722
11.	Montreal	1857	351	946
12.	Baltimore	1858	190	962
13.	Springfield	1859	190	862
14.	Newport	1860	135	644
15.	Buffalo	1866	79	637
16.	Burlington	1867	73	415
17.	Chicago	1868	259	086
18.	Salem	1869	244	511
19.	Troy	1870	188	536
20.	Indianapolis	1871	196	668
21.	Dubuque	1871	164	610
22.	Portland	1873	195	670
23.	Hartford	1874	224	722
24.	Detroit	1875	165	807
25.	2nd Buffalo	1876	215	867
26.	Nashville	1877	173	953
27.	St. Louis	1878	134	962
28.	Saratoga	1879	256	1030
29.	Boston	1880	997	1555
30.	2nd Cincinnati	1881	500	1699
31.	2nd Montreal	1882	937	1922
32.	Minneapolis	1883	328	2033
33.	2nd Philadelphia	1884	1261*	1981
34.	Ann Arbor	1885	364	1956
35.	3d Buffalo	1886	445	1880
36.	New York	1887	729	1956
37.	2nd Cleveland	1888	342	1964
38.	Toronto	1889	424	1952
39.	2d Indianapolis.	1890	364	1944
40.	2d Washington.	1891	653†	2054

*Including members of the British Association and other foreign guests.
†Including twenty-four foreign Honorary members for the meeting.

COMMONWEALTH OF MASSACHUSETTS.

IN THE YEAR ONE THOUSAND EIGHT HUNDRED AND SEVENTY-FOUR.

AN ACT

To Incorporate the "American Association for the Advancement of Science."

Be it enacted by the Senate and House of Representatives, in General Court assembled, and by the authority of the same, as follows:

Section 1. Joseph Henry of Washington, Benjamin Pierce of Cambridge, James D. Dana of New Haven, James Hall of Albany, Alexis Caswell of Providence, Stephen Alexander of Princeton, Isaac Lea of Philadelphia, F. A. P. Barnard of New York, John S. Newberry of Cleveland, B. A. Gould of Cambridge, T. Sterry Hunt of Boston, Asa Gray of Cambridge, J. Lawrence Smith of Louisville, Joseph Lovering of Cambridge and John LeConte of Philadelphia, their associates, the officers and members of the Association, known as the "American Association for the Advancement of Science," and their successors, are hereby made a corporation by the name of the "American Association for the Advancement of Science," for the purpose of receiving, purchasing, holding and conveying real and personal property, which it now is, or hereafter may be, possessed of, with all the powers and privileges, and subject to the restrictions, duties and liabilities set forth in the general laws which now or hereafter may be in force and applicable to such corporations.

Section 2. Said corporation may have and hold by purchase, grant, gift or otherwise, real estate not exceeding one hundred thousand dollars in value, and personal estate of the value of two hundred and fifty thousand dollars.

Section 3. Any two of the corporators above named are hereby authorized to call the first meeting of the said corporation in the month of August next ensuing, by notice thereof "by mail," to each member of the said Association.

Section 4. This act shall take effect upon its passage.

House of Representatives, March 10, 1874.
Passed to be enacted,
John F. Sanford, *Speaker.*

In Senate, March 17, 1874.
Passed to be enacted.
Geo. B. Loring, *President.*

March 19, 1874.
Approved,
W. B. Washburn.

Secretary's Department,
Boston, April 3, 1874.
A true copy, Attest:
David Pulsifer,
Deputy Secretary of the Commonwealth.

CONSTITUTION

OF THE

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

Incorporated by Act of the General Court of the Commonwealth of Massachusetts.

OBJECTS.

ARTICLE 1. The objects of the Association are, by periodical and migratory meetings, to promote intercourse between those who are cultivating science in different parts of America, to give a stronger and more general impulse and more systematic direction to scientific research, and to procure for the labors of scientific men increased facilities and a wider usefulness.

MEMBERS, FELLOWS, PATRONS AND HONORARY FELLOWS.

ART. 2. The Association shall consist of Members, Fellows, Patrons, Corresponding Members and Honorary Fellows.

ART. 3. Any person may become a Member of the Association upon recommendation in writing by two members or fellows, and election by the Council.

ART. 4. Fellows shall be elected by the Council from such of the members as are professionally engaged in science, or have by their labors aided in advancing science. The election of fellows shall be by ballot and a majority vote of the members of the Council at a designated meeting of the Council.

ART. 5. Any person paying to the Association the sum of one thousand dollars shall be classed as a Patron, and shall be entitled to all the privileges of a member and to all its publications.

ART. 6. Honorary Fellows of the Association, not exceeding three for each section, may be elected; the nominations to be made by the Council and approved by ballot in the respective sections before election by ballot in General Session. Honorary Fellows shall be entitled to all the privileges of Fellows and shall be exempt from all fees and assessments, and entitled to all publications of the Association issued after the date of their election. Corresponding Members shall consist of such scientists not re-

siding in America as may be elected by the Council, and their number shall be limited to fifty. Corresponding Members shall be entitled to all the privileges of members and to the annual volumes of Proceedings published subsequent to their election.

ART. 7. The name of any member or fellow two years in arrears for annual dues shall be erased from the list of the Association, provided that two notices of indebtedness, at an interval of at least three months, shall have been given; and no such person shall be restored until he has paid his arrearages or has been reëlected. The Council shall have power to exclude from the Association any member or fellow, on satisfactory evidence that said member or fellow is an improper person to be connected with the Association, or has in the estimation of the Council made improper use of his membership or fellowship.

ART. 8. No member or fellow shall take part in the organization of, or hold office in, more than one section at any one meeting.

OFFICERS.

ART. 9. The Officers of the Association shall be elected by ballot in General Session from the fellows, and shall consist of a President, a Vice-President from each section, a Permanent Secretary, a General Secretary, a Secretary of the Council, a Treasurer, and a Secretary of each Section; these, with the exception of the Permanent Secretary, shall be elected at each meeting for the following one, and, with the exception of the Treasurer and the Permanent Secretary, shall not be reëligible for the next two meetings. The term of office of Permanent Secretary shall be five years.

ART. 10. The President, or, in his absence, the senior Vice President present, shall preside at all General Sessions of the Association and at all meetings of the Council. It shall also be the duty of the President to give an address at a General Session of the Association at the meeting following that over which he presided.

ART. 11. The Vice Presidents shall be chairmen of their respective Sections, and of their Sectional Committees, and it shall be part of their duty to give an address, each before his own section, at such time as the Council shall determine. The Vice Presidents may appoint temporary chairmen to preside over the sessions of their sections, but shall not delegate their other duties. The Vice Presidents shall have seniority in order of their continuous membership in the Association.

ART. 12. The General Secretary shall be the Secretary of all General Sessions of the Association, and shall keep a record of the business of

these sessions. He shall receive the records from the Secretaries of the Sections, which, after examination, he shall transmit with his own records to the Permanent Secretary within two weeks after the adjournment of the meeting.

ART. 13. The Secretary of the Council shall keep the records of the Council. He shall give to the Secretary of each Section the titles of papers assigned to it by the Council. He shall receive proposals for membership and bring them before the Council.

ART. 14. The Permanent Secretary shall be the executive officer of the Association under the direction of the Council. He shall attend to all business not specially referred to committees nor otherwise constitutionally provided for. He shall keep an account of all business that he has transacted for the Association, and make annually a general report for publication in the annual volume of Proceedings. He shall attend to the printing and distribution of the annual volume of Proceedings, and all other printing ordered by the Association. He shall issue a circular of information to members and fellows at least three months before each meeting, and shall, in connection with the Local Committee, make all necessary arrangements for the meetings of the Association. He shall provide the Secretaries of the Association with such books and stationery as may be required for their records and business, and shall provide members and fellows with such blank forms as may be required for facilitating the business of the Association. He shall collect all assessments and admission fees, and notify members and fellows of their election, and of any arrearages. He shall receive, and bring before the Council, the titles and abstracts of papers proposed to be read before the Association. He shall keep an account of all receipts and expenditures of the Association, and report the same annually at the first meeting of the Council, and shall pay over to the Treasurer such unexpended funds as the Council may direct. He shall receive and hold in trust for the Association all books, pamphlets and manuscripts belonging to the Association, and allow the use of the same under the provisions of the Constitution and the orders of the Council. He shall receive all communications addressed to the Association during the interval between meetings, and properly attend to the same. He shall at each meeting report the names of fellows and members who have died since the preceding meeting. He shall be allowed a salary which shall be determined by the Council, and may employ one or more clerks at such comp ensation as may be agreed upon by the Council.

ART. 15. The Treasurer shall invest the funds received by him in such securities as may be directed by the Council. He shall annually present to the Council an account of the funds in his charge. No expenditure of the principal in the hands of the Treasurer shall be made without a unanimous vote of the Council, and no expenditure of the income received by the Treasurer shall be made without a two-thirds vote of the Council.

ART. 16. The Secretaries of the Sections shall keep the records of their respective sections, and, at the close of the meeting, give the same, including the records of subsections, to the General Secretary. They shall also be the Secretaries of the Sectional Committees. The Secretaries shall have seniority in order of their continuous membership in the Association.

ART. 17. In case of a vacancy in the office of the President, one of the Vice Presidents shall be elected by the Council as the President of the meeting. Vacancies in the offices of Vice President, Permanent Secretary, General Secretary, Secretary of the Council, and Treasurer, shall be filled by nomination of the Council and election by ballot in General Session. A vacancy in the office of Secretary of a Section shall be filled by nomination and election by ballot in the Section.

ART. 18. The Council shall consist of the past Presidents, and the Vice Presidents of the last meeting, together with the President, the Vice Presidents, the Permanent Secretary, the General Secretary, the Secretary of the Council, the Secretaries of the Sections, and the Treasurer of the current meeting, with the addition of one fellow elected from each Section by ballot on the first day of its meeting. The members present at any regularly called meeting of the Council, provided there are at least five, shall form a quorum for the transaction of business. The Council shall meet on the day preceding each annual meeting of the Association, and arrange the programme for the first day of the sessions. The time and place of this first meeting shall be designated by the Permanent Secretary. Unless otherwise agreed upon, regular meetings of the Council shall be held in the council room at 9 o'clock, A. M., on each day of the meeting of the Association. Special meetings of the Council may be called at any time by the President. The Council shall be the board of supervision of the Association, and no business shall be transacted by the Association that has not first been referred to, or originated with, the Council. The Council shall receive and assign papers to the respective sections; examine and, if necessary, exclude papers; decide which papers, discussions and other proceedings shall be published, and have the general direction of the pub-

lications of the Association; manage the financial affairs of the Association: arrange the business and programmes for General Sessions; suggests subjects for discussion, investigation or reports; elect members and fellows; and receive and act upon all invitations extended to the Association and report the same at a General Session of the Association. The Council shall receive all reports of Special Committees and decide upon them, and only such shall be read in General Session as the Council shall direct. The Council shall appoint at each meeting the following sub-committees who shall act, subject to appeal to the whole Council, until their successors are appointed at the following meeting: 1, on Papers and Reports; 2, on Members; 3, on Fellows.

ART. 19. The Nominating Committee shall consist of the Council, and one member or fellow elected by each of the Sections. It shall be the duty of this Committee to meet at the call of the President and nominate the general officers for the following meeting of the Association. It shall also be the duty of this Committee to recommend the time and place for the next meeting. The Vice President and Secretary of each Section shall be recommended to the Nominating Committee by a sub-committee consisting of the Vice President, Secretary, and three members or fellows elected by the Section.

MEETINGS.

ART. 20. The Association shall hold a public meeting annually, for one week or longer, at such time and place as may be determined by vote of the Association, and the preliminary arrangements for each meeting shall be made by the Local Committee, in conjunction with the Permanent Secretary and such other persons as the Council may designate.

ART. 21. A General Session shall be held at 10 o'clock A. M., on the first day of the meeting, and at such other times as the Council may direct.

SECTIONS AND SUBSECTIONS.

ART. 22. The Association shall be divided into Sections, namely:— A, *Mathematics and Astronomy;* B, *Physics;* C, *Chemistry, including its application to agriculture and the arts;* D, *Mechanical Science and Engineering;* E, *Geology and Geography;* F, *Biology;* [G, united to section F]; H, *Anthropology;* I, *Economic Science and Statistics.* The Council shall have power to consolidate any two or more Sections temporarily, and such consolidated Sections shall be presided over by the senior Vice President and Secretary of the Sections comprising it.

ART. 23. Immediately on the organization of a Section there shall be three fellows elected by ballot after open nomination, who, with the Vice President and Secretary, shall form its Sectional Committee. The Sectional Committees shall have power to fill vacancies in their own numbers. Meetings of the Sections shall not be held at the same time with a General Session.

ART. 24. The Sectional Committee of any Section may at its pleasure form one or more temporary Subsections, and may designate the officers thereof. The Secretary of a Subsection shall, at the close of the meeting, transmit his records to the Secretary of the Section.

ART. 25. A paper shall not be read in any Section or Subsection until it has been received from the Council and placed on the programme of the day by the Sectional Committee.

SECTIONAL COMMITTEES.

ART. 26. The Sectional Committees shall arrange and direct the business of their respective Sections. They shall prepare the daily programmes and give them to the Permanent Secretary for printing at the earliest moment practicable. No titles of papers shall be entered on the daily programmes except such as have passed the Council. No change shall be made in the programme for the day in a Section without the consent of the Sectional Committee. The Sectional Committees may refuse to place the title of any paper on the programme; but every such title, with the abstract of the paper or the paper itself, must be returned to the Council with the reasons why it was refused.

ART. 27. The Sectional Committees shall examine all papers and abstracts referred to the sections, and they shall not place on the programme any paper inconsistent with the character of the Association; and to this end they have power to call for any paper, the character of which may not be sufficiently understood from the abstract submitted.

PAPERS AND COMMUNICATIONS.

ART. 28. All members and fellows must forward to the Permanent Secretary, as early as possible, and when practicable before the convening of the Association, full titles of all the papers which they propose to present during the meeting, with a statement of the time that each will occupy in delivery, and also such abstracts of their contents as will give a general idea of their nature; and no title shall be referred by the Council to the Sectional Committee until an abstract of the paper or the paper itself has been received.

ART. 29. If the author of any paper be not ready at the time assigned, the title may be dropped to the bottom of the list.

ART. 30. Whenever practicable, the proceedings and discussions at General Sessions, Sections and Subsections shall be reported by professional reporters, but such reports shall not appear in print as the official reports of the Association unless revised by the Secretaries.

PRINTED PROCEEDINGS.

ART. 31. The Permanent Secretary shall have the Proceedings of each meeting printed in an octavo volume as soon after the meeting as possible, beginning one month after adjournment. Authors must prepare their papers or abstracts ready for the press, and these must be in the hands of the Secretaries of the Sections before the final adjournment of the meeting, otherwise only the titles will appear in the printed volume. The Council shall have power to order the printing of any paper by abstract or title only. Whenever practicable, proofs shall be forwarded to authors for revision. If any additions or substantial alterations are made by the author of a paper after its submission to the Secretary, the same shall be distinctly indicated. Illustrations must be provided for by the authors of the papers, or by a special appropriation from the Council. Immediately on publication of the volume, a copy shall be forwarded to every member and fellow of the Association who shall have paid the assessment for the meeting to which it relates, and it shall also be offered for sale by the Permanent Secretary at such price as may be determined by the Council. The Council shall also designate the institutions to which copies shall be distributed.

LOCAL COMMITTEE.

ART. 32. The Local Committee shall consist of persons interested in the objects of the Association and residing at or near the place of the proposed meeting. It is expected that the Local Committee, assisted by the officers of the Association, will make all essential arrangements for the meeting, and issue a circular giving necessary particulars, at least one month before the meeting.

LIBRARY OF THE ASSOCIATION.

ART. 33. All books and pamphlets received by the Association shall be in the charge of the Permanent Secretary, who shall have a list of the same printed and shall furnish a copy to any member or fellow on application. Members and fellows who have paid their assessments in full shall be allowed to call for books and pamphlets, which shall be delivered

to them at their expense, on their giving a receipt agreeing to make good any loss or damage and to return the same free of expense to the Secretary at the time specified in the receipt given. All books and pamphlets in circulation must be returned at each meeting. Not more than five books, including volumes, parts of volumes, and pamphlets, shall be held at one time by any member or fellow. Any book may be withheld from circulation by order of the Council.

Admission Fee and Assessments.

Art. 34. The admission fee for members shall be five dollars in addition to the annual assessment. On the election of any member as a fellow an additional fee of two dollars shall be paid.

Art. 35. The annual assessment for members and fellows shall be three dollars.

Art. 36. Any member or fellow who shall pay the sum of fifty dollars to the Association, at any one time, shall become a Life Member and as such shall be exempt from all further assessments, and shall be entitled to the Proceedings of the Association. All money thus received shall be invested as a permanent fund, the income of which, during the life of the member, shall form a part of the general fund of the Association; but, after his death, shall be used only to assist in original research, unless otherwise directed by unanimous vote of the Council.

Art. 37. All admission fees and assessments must be paid to the Permanent Secretary, who shall give proper receipts for the same.

Accounts.

Art. 38. The accounts of the Permanent Secretary and of the Treasurer shall be audited annually, by Auditors appointed by the Council.

Alterations of the Constitution.

Art. 39. No part of this Constitution shall be amended or annulled, without the concurrence of three-fourths of the members and fellows present in General Session, after notice given at a General Session of a preceding meeting of the Association.

MEMBERS

OF THE

AMERICAN ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE.[1]

PATRONS.[2]

THOMPSON, MRS. ELIZABETH, Stamford, Conn. (22).
LILLY, GEN. WILLIAM, Mauch Chunk, Carbon Co., Pa. (28) F E
HERRMAN, MRS. ESTHER, 59 West 56th St., New York, N. Y. (29).

CORRESPONDING MEMBERS.[3]

Macfarlane, Dr. John M., Lansdowne, Del. Co., Pa. (40). F
Monselise, Prof. G., Via Principe Amedeo I, Milano, Italy (40). C
Warington, Robert, F.R.S., Rothamsted, Harpenden, England (40). C

MEMBERS.[4]

Abbe, Robert, 11 W. 50th St., New York, N. Y. (36).
Abrey, George Burchutt, C.E., Toronto, Ontario, Can. (38).
Acker, Dr. Geo. N., 913 16th St., Washington, D. C. (40). F
Adriance, John S., 2 West 36 St., New York, N. Y. (39). C
Agard, Dr. A. H., 1259 Alice St., Oakland, Alameda Co., Cal. (28).
Aitkin, Miss Clara I., 210 Madison St., Brooklyn, N. Y. (40). H
Aitkin, Miss Helen J., 210 Madison St., Brooklyn, N. Y. (40). E H

[1] The numbers in parentheses indicate the meeting at which the member was elected. The black letters at the end of line indicate the sections to which members elect to belong. The Constitution requires that the names of all members two or more years in arrears shall be omitted from the list, but their names will be restored on payment of arrearages. Members not in arrears are entitled to the annual volume of Proceedings bound in paper. *The payment of ten dollars at one time entitles a member to the subsequent volumes to which he may be entitled, bound in cloth, or by the payment of twenty dollars, to such volumes bound in half morocco.*

[2] Persons contributing one thousand dollars or more to the Association are classed as Patrons, and are entitled to the privileges of members and to the publications.

The names of Patrons are to remain permanently on the list.

[3] See ARTICLE VI of the Constitution.

[4] Any Member or Fellow may become a Life Member by the payment of fifty dollars. The income of the money derived from a Life Membership is used for the general purposes of the Association during the life of the member; afterwards it is to be used to aid in original research. Life Members are exempt from the annual assessment, and are entitled to the annual volume. The names of Life Members are printed in small capitals in the regular list of Members and Fellows.

Alden, Jno., Pacific Mills, Lawrence, Mass. (36).
Allderdice, Wm. H., Ass't Eng. U. S. N., U. S. Naval Academy, Annapolis, Md. (33). D
Allen, J. M., Hartford, Conn. (22). D
Allen, W. F., 24 Park Place, New York, N. Y. (36).
Allen, Walter S., New Bedford, Mass. (39). C I
Ammidown, Edward H., P. O. Box 2739, New York, N. Y. (37).
Anderson, Alexander D., Washington, D. C. (38).
Angell, Geo. W. J., 44 Hudson St., New York, N. Y. (36).
Ansley, Clark F., Swedona, Mercer Co., Ill. (32). E H
Appleton, Rev. Edw. W., D.D., Ashbourne, Montgomery Co., Pa. (28).
Archambault, U. E., P. O. Box 1944, Montreal, P. Q., Can. (31).
Archbold, George, 1224 B St., S. E., Washington, D. C. (40).
Armstrong, Mrs. Lucius H., St. Nicholas, Duval Co., Fla. (30).
Ashmead, Wm. H., 825 Vermont Ave., Washington, D. C. (40). F
Atkinson, George F., Auburn, Ala. (39). F
Atkinson, Jno. B., Earlington, Hopkins Co., Ky. (26). D
Auhagen, Wilhelm, Mt. Pleasant, 17th St. ext., Washington, D. C. (40).
Austin, H. W., No. 3 B St., S. E., Washington, D. C. (40). C
Austin, Wm., Belvidere House, 4th Ave., cor. 18th St., New York, N. Y. (36).
Avery, Robert Stanton, 320 A St., S. E., Washington, D. C. (40). A
Avery, Samuel P., 4 E. 38th St., New York, N. Y. (36).
Ayer, Edward Everett, Room 12, The Rookery, Chicago, Ill. (37). H
Ayres, Horace B., Allamuchy, N. J. (40).

Babcock, Wm. H., Washington, D. C. (40).
Bain, James, jr., Toronto, Ontario, Can. (38).
Baker, Philip S., M.D., DePauw University, Greencastle, Ind. (39). C
Baker, Richard D., 112 So. 21st St., Philadelphia, Pa. (33). E C
Baker, Wm. G., 234 E. 15th St., New York, N. Y. (36).
Balderston, C. Canby, Westtown, Chester Co., Pa. (33). B
Baldwin, Miss Mary A., 28 Fulton St., Newark, N. J. (31). E
Baldwin, Mrs. G. H., 3 Madison Ave., Detroit, Mich. (34). H
Banes, Charles H., 1107 Market St., Philadelphia, Pa. (31). D
Bangs, Lemuel Bolton, M.D., 127 E. 34th St., New York, N. Y. (36).
Barber, D. H., Marion, Iowa (37).
Barclay, Robert, A.M., M.D., 3211 Lucas Ave., St. Louis, Mo. (30).
Bardeen, Francis L., M.D., Box 76, Onondaga Hill, N. Y. (32). C F B
Barge, B. F., Mauch Chunk, Pa. (33).
Barker, Francis C., 200 D St., N. W., Washington, D. C. (40). E
Barker, Mrs. Martha M., 26 Eleventh St., Lowell, Mass. (31). E H
Barnes, Hon. Willis L., Charlestown, Ind. (40). A B
Barnum, Miss Charlotte C., 144 Humphrey St., New Haven, Conn. (36). A
Barrett, Fred. P., 1012 N. 41st St., Philadelphia. Pa. (40). E
Barringer, Daniel M., Bullitt Building, Philadelphia, Pa. (40). C E
Barrows, Walter B., Dept. of Agric., Washington, D. C. (40). F

Bartley, Elias H., M.D., 21 Lafayette Ave., Brooklyn, N. Y. (33). C
Bass, Wm. H., 393 College Ave., Indianapolis, Ind. (39). D
Bastin, Edson Sewell, 3330 S. Park Ave., Chicago, Ill. (39).
Bates, Prof. Clinton Owen, Cedar Rapids, Iowa (38).
Bates, Wm. W., Com. of Navigation, Washington, D. C. (38).
Batterson, J. G., Hartford, Conn. (23).
Bauer, Louis A., U. S. Coast and Geodetic Survey, Washington, D. C. (40). A
Baxter, James N., 18 Fulton St., Brooklyn, N. Y. (36).
Beach, William H., Madison, Wis. (21). E B
Beale, Oscar J., care Brown & Sharpe, Providence, R. I. (39). D
Beall, Fielder, M. M., Lieut. U. S. A., Auditorium Building, Chicago, Ill. (40).
Bean, B. A., Ass't Curator, Dept. of Fishes, National Museum, Washington, D. C. (40). F
Bean, Thos. E., Box 441, Galena, Ill. (28). F
Beaver, Daniel B. D., M.D., 150 North 6th St., Reading, Pa. (39).
Bechdolt, Adolphus F., Supt. City Schools, Mankato, Minn. (32). E B F
Bell, C. M., M.D., 320 Fifth Ave., New York, N. Y. (36).
Belt, R. V., 1314 10th St., N. W., Washington, D. C. (40).
Benner, Henry, N. W. University, Evanston, Ill. (40). A
Bennett, Charles M., Logansport, Ind. (39).
Benns, Chas. P., Schenectady, N. Y. (38). D
Benton, George W., High School, Indianapolis, Ind. (39). C
Beveridge, David, 145 Griswold St., Detroit, Mich. (33). I
Biddle, James G., 924 Chestnut St., Philadelphia, Pa. (39).
Bien, Julius, 139 Duane St., New York, N. Y. (34). E H
Bigelow, Miss Clarissa, Kalamazoo, Mich. (39). A
Biggar, Hamilton F., M.D., 176 Euclid Ave., Cleveland, Ohio (40). B F
Bigney, Prof. A. J., Moore's Hill, Ind. (40). F
Bingham, Mrs. Martha A. (32).
Birdsall, Miss Louise W., 105 E. 37th St., New York, N. Y. (37). F E
Bishop, Heber R., Mills Building, New York, N. Y. (36).
Bixby, Wm. H., Capt. of Eng., U. S. A., Wilmington, N. C. (34). D
Blackstock, Rev. W. S., 20 Homewood Ave., Toronto, Ont., Can. (38). E
Blackwell, Mrs. A. B., Elizabeth, N. J. (30). F C B
Blair, Mrs. Eliza N., 213 E. Capitol St., Washington, D. C. (40).
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Sullivan, J. A., care Dr. Sullivan, 310 Main St., Malden, Mass. (27). A
Sullivan, J. C., M.D., Cairo, Ill. (40). A
Swasey, Oscar F., M.D., Beverly, Mass. (17).
Sweet, Henry N., 89 State St., Boston, Mass. (40). H D
Sweetnam, Geo. Booker, 39 St. Vincent St., Toronto, Ontario, Can. (38).
Swingle, W. T., Dept. of Agric., Washington, D. C. (40). F
Symons, Harry, 4 Howard St., Toronto, Ontario, Can. (38).

Taft, Charles E., care Census Bureau, Washington, D. C. (37). E
Taft, Mrs. Charles E., care Census Bureau, Washington, D. C. (37). B
Taft, Elihu B., Burlington, Vt. (36). H
Talbott, Mrs. Laura Osborne, 927 P St., Washington, D. C. (36).
Talbott, Dr. Thomas M., 927 P St., Washington, D. C. (40).
Talbutt, John H., Lexington, Ky. (38).
Taylor, Edward Randolph, Cleveland, Ohio (39). C
Taylor, F. B., Box 2019, Fort Wayne, Ind. (39).
Taylor, Prof. Jas. M., Hamilton, Madison Co., N. Y. (33). A D
Taylor, Robert S., Box 2019, Fort Wayne, Ind. (39).
Taylor, William Alton, 1228 14th St., Washington, D. C. (40).
Teller, George L., Fayetteville, Washington Co., Ark. (40). C
Thompson, Alton Howard, 721 Kansas Ave., Topeka, Kan. (33). H F
Thompson, Daniel G., 120 Broadway, New York, N. Y. (29).
Thompson, Mrs. Ellen P., 1729 12th St., Washington, D. C. (40). H
Thompson, Prof. Edw. P., Beaver Falls, Pa. (37). A
Thompson, Mrs. Frank, 233 South 4th St., Philadelphia, Pa. (33).
Thompson, Fred'k F., 283 Madison Ave., New York, N. Y. (36).
Thompson, Harvey M., Ross House, Oakland, Cal. (17).

Thompson, J. L., M.D., Indianapolis, Ind. (39). F
Thompson, Robert Allen, Collegiate Inst., Hamilton, Ont., Can. (38). A
Thruston, R. C. Ballard, Louisville, Ky. (36). E
Thurtle, J. G., Indianapolis, Ind. (39).
Thwing, Charles B., Northwestern Univ., Evanston, Ill. (38). B
Tiffany, Asa S., 901 West 5th St., Davenport, Scott Co., Iowa (27). E H
Tight, Prof. William George, Granville, Ohio (39). F
Tindall, Willoughby C., Associate Prof. of Math., Univ. of Missouri, Columbia, Mo. (40).
Todd, Albert M., Nottawa, Mich. (37). C
Townsend, Clinton P., Donaldsonville, La. (40). C
Townsend, Franklin, 4 Elk St., Albany, N. Y. (4).
Townsend, Henry C., 709 Walnut St., Philadelphia, Pa. (33). I
Treat, Erastus B., Publisher and Bookseller, 5 Cooper Union, cor. 4th Ave. and 8th St., New York, N. Y. (29). F I
Trenholm, Hon. W. L., Pres. Amer. Surety Co., 160 Broadway, New York, N. Y. (35).
Trescot, T. C., 1418 L St., Washington, D. C. (40). C
Trowbridge, Luther H., 266 Woodward Ave., Detroit, Mich. (29).
Trowbridge, Mrs. L. H., 266 Woodward Ave., Detroit, Mich. (21).
Tryon, F. M., Room 120, Patent Office, Washington, D. C. (40).
Tudor, Prof. Joseph H., Florence, N. J. (39).
Tullock, Alonzo J., Engineer, Leavenworth, Kansas (35). D
Turnbull, Mungo, 18 Denison Square, Toronto, Ontario, Can. (38). A E
Turner, Dr. E. Marsh, Pres. W. Va. Univ., Morgantown, W. Va. (40). I
Turner, Henry Ward, Valley Springs, Cal. (34). E

Ulrey, Albert B., North Manchester, Ind. (39). F
Updegraff, Milton, Observatory, Columbia, Mo. (40). A

Vail, Prof. Hugh D., Santa Barbara, Cal. (18).
Valentine, Benj. B., Richmond, Va. (33). H
Valentine, Edw. P., Richmond, Va. (33). H
Van Beuren, Frederick T., 21 W. 14th St., New York, N. Y. (36).
Van Brunt, Cornelius, 319 E. 57th St., New York, N. Y. (28).
Van Vleck, Frank, Pacific Railway Co., Los Angeles, Cal. (35). D
Varney, Miss May, Simon, Wayne Co., Pa. (40).
Vaux, Geo., jr., 404 Girard Building, Philadelphia, Pa. (33). E A
Veeder, Major Albert, M.D., Lyons, Wayne Co., N. Y. (36).
Vermyné, J. J. B., M.D., 2 Orchard St., New Bedford, Mass. (29). F
Vieth, William, cor. 8th and Freeman Sts., Cincinnati, O. (28).
Villard, Fanny G., Dobbs Ferry, N. Y. (36).
Vinal, W. Irving, 1106 A St., N. E., Washington, D. C. (40). E
Voorhees, Chas. H., M.D., P. O. Lock Box 120, New Brunswick, N. J. (29). F H
Vredenburgh, Edw. H., Rochester, N. Y. (29).

Wadsworth, H. L., 1209 17th St., Denver, Col. (39). D

Wagenhals, Samuel, Box 382, Fort Wayne, Ind. (40). H
Wagner, Frank C., care Wm. Wagner, Ann Arbor, Mich. (34). D
Waite, M. B., Dep't of Agriculture, Washington, D. C. (37).
Wales, Salem H., 25 E. 55th St., New York, N. Y. (36).
Walker, Byron Edmund, Toronto, Ontario, Can. (38). E
Walker, George C., 228 Michigan Ave., Chicago, Ill. (17).
Walker, Philip, Dep't of Agric., Division of Entomology, Silk Culture, Washington, D. C. (33). B D
Wall, John L., 338 Sixth Avenue, New York, N. Y. (27). F
Walter, Robert, M.D., Walter's Park P. O., Wernersville, Pa. (33). F H
Walton, Jos. R., M.D., 1921 Pennsylvania Ave., Washington, D. C. (40).
Walworth, Rev. Clarence A., 41 Chapel St., Albany, N. Y. (28). E
Wanamaker, John, Postmaster General, Washington, D. C. (33).
Wappenhaus, C. F. R., Signal Office, Indianapolis, Ind. (39). B
Ward, Frank A., 16-26 College Ave., Rochester, N. Y. (40).
Ward, J. Langdon, 120 Broadway, New York, N. Y. (29). I
Ward, Samuel B., M.D., Albany, N. Y. (29). F C A
Wardwell, George J., Rutland, Vt. (20). D E
Ware, Wm. R., Columbia College, New York, N. Y. (36).
Waring, John, Manchester, Conn. (33). D B
Warner, Prof. A. G., District Offices, Washington, D. C. (38).
Warner, Hulbert H., Rochester, N. Y. (31). A
Warren, Eugene C., 611 W. Main St., Louisville, Ky. (37).
Warren, Mrs. Susan E., 67 Mt. Vernon St., Boston, Mass. (29).
Warrington, James N., Vulcan Iron Works, 86 No. Clinton St., Chicago, Ill. (34). D A B
Waterhouse, A., M.D., 42 Allen St., Jamestown, N. Y. (29). F
Waterman, L. D., M.D., Indianapolis, Ind. (39). F
Waters, Edwin F., 131 Newbury St., Boston, Mass. (29).
Waters, Geo. F., 6 Somerset St., Boston, Mass. (29). B F H E D
Watkins, John E., C. E., National Museum, Washington, D. C. (40) D
Watkins, L. D., Manchester, Mich. (34). C
Watson, Miss C. A., Salem, Mass. (31). D
Watters, William, M. D., 26 So. Common St., Lynn, Mass. (40).
Weaver, Gerrit E. Hambleton, A.M., 300 So. 36 St., Philadelphia, Pa. (38). F
Weed, H. E., Agricultural College, Miss. (40). F
Weed, J. N., Newburgh, N. Y. (37). E I
Weeden, Hon. Joseph E., Randolph, Cattaraugus Co., N. Y. (31).
Weeks, Joseph D., Editor American Manufacturer, Pittsburgh, Pa. (35). D
Welch, Thomas V., Superintendent State Reservation, Niagara Falls, N.Y. (35).
Wells, Amos R., Antioch College, Yellow Springs, Ohio (38).
Wells, Mrs. C. F., 775 Broadway, New York, N. Y. (31). H F I D B
Wells, Samuel, 31 Pemberton Square, Boston, Mass. (24). H
Wells, William H., jr., 274 Ashland Ave., Chicago, Ill. (39). E

Werum, Jno. H., Toledo, Ohio (40).
West, Miss Nellie B., 875 Madison Ave., New York, N. Y. (38). E
Westbrook, Benj. F., M.D., 174 Clinton St., Brooklyn, N. Y. (33).
Wetzler, Jos., Room 175, Potter Building, New York, N. Y. (36).
Wheeler, Herbert A., Washington Univ., St. Louis, Mo. (33). E I
Wheeler, T. B., M.D., 194 Mountain St., Montreal, P. Q., Can. (11).
Wheildon, Miss Alice W., Concord, Mass. (31).
Whelen, Edw. S., 1520 Walnut St., Philadelphia, Pa. (33).
Whetstone, John L., Summit Ave., Mt. Auburn, Cincinnati, Ohio (30). D
White, Charles H., Med. Inspector U.S.N., care A. B. Gilman, Bradford, Mass. (34). C
White, David, U. S. Geol. Survey, Washington, D. C. (40). E F
White, James G., 29 Broadway, New York, N. Y. (34). B A
White, LeRoy S., Box 324, Waterbury, Conn. (23).
White, Loomis L., 7 E. 44th St., New York, N. Y. (36).
Whiting, Mrs. Francis, Jeffersonville, Montgomery Co., Pa. (40).
Whiting, S. B., 11 Ware St., Cambridge, Mass. (33). D
Whitlock, Prof. Roger H., Coll. Station, Brazos Co., Texas (36). A B D
Whitney, Joseph T., Ohio State Univ., Columbus, Ohio (40).
Wickersham, Jas. A., Rose Polytechnic Inst., Terre Haute, Ind. (39). H
Wilbor, Rev. W. C., Ph.D., 498 W. Ferry St., Buffalo, N. Y. (39). F
Wilbour, Mrs. Charlotte B., Little Compton, R. I. (28).
Wilcox, Miss Emily T., 85 Second St., Troy, N. Y. (33). B A
Wilder, Alex., M.D., 565 Orange St., Newark, N. J. (29). H F I
Wilkinson, Ernest, Washington, D. C. (40).
Wilkinson, J. Henderson, 320 E. Capitol St., Washington, D. C. (35). E
Wilkinson, Mrs. L. V., Seventy Six P. O., Perry Co., Mo. (30).
Willetts, Joseph C., Skaneateles, N. Y. (29). E F H
Willitts, George E., Lansing, Mich. (39). F
Willits, Edwin, Dept. of Agriculture, Washington, D. C. (40). I
Williams, Prof. Edward H., jr., Box 463, Bethlehem, Pa. (25). E D
Wilmarth, Mrs. Henry D., 51 Eliot St., Jamaica Plain, Mass. (40).
Wilmot, Thos. J., Commercial Cable Co., Waterville, County Kerry, Ireland (27). B
Wilson, Herbert M., U. S. Geol. Survey, Washington, D. C. (40). D E
Windle, Prof. W. S., College Springs, Iowa (39). F
Wingate, Miss Hannah S., 42 Ashland Place, Brooklyn, N. Y. (31). E I
Winterhalter, A. G., Lt. U. S. N., care Navy Dept., Washington, D. C. (37). A
Wisser, John P., 1st Lt. 1st Artillery, U. S. A., West Point, N. Y. (33). C
Witt, Carl C., Indianapolis, Ind. (39).
Witton, James G., B.A., University Coll., Toronto, Ontario, Can. (38). B
Wolcott, Mrs. Henrietta L. T., Dedham, Mass. (29).
Wolff, Dr. J. E., 15 Story St., Cambridge, Mass. (36).
Wood, Alvinus B., 980 Jefferson Ave., Detroit, Mich. (34). E
Wood, Joseph S., Mount Vernon, Westchester Co., N. Y. (36).
Wood, Norman B., jr., 67½ University St., Cleveland, Ohio (38).

Wood, Dr. Robert W., Jamaica Plain, Mass. (29).
Wood, Walter, 400 Chestnut St., Philadelphia, Pa. (33). F I
Wrenshall, John C., Baltimore, Md. (40). H
Würtele, Miss Minnie, Acton Vale, P. Q., Can. (32). H
Wyman, Walter, M.D., Supervising Surg. Gen., U. S. Marine Hospital Service, Washington, D. C. (40). I
Wyman, Walter Channing, 158 Dearborn St., Chicago, Ill. (34). H

Yeates, W. S., U. S. National Museum, Washington, D. C. (40).
York, Mrs. Margaret M., 937 Westminster St., Washington, D. C. (40). H
Youmans, Mrs. Celia G., Mount Vernon, N. Y. (36).
Young, Prof. A. Harvey, Hanover College, Hanover, Ind. (30). F C
Young, Archibald Hope, Upper Canada College, Toronto, Ontario, Can. (38).

[1275 Patrons, Corresponding Members and Members.]

Note.—The omission of an address in the foregoing list indicates that letters directed to that last printed were returned as uncalled for. Information of the present address of the members so indicated is requested by the Permanent Secretary.

HONORARY FELLOWS.[1]

ROGERS, WILLIAM B., Boston, Mass. (1). 1881. (Born Dec. 7, 1804. Died May 30, 1882.) **B E**

CHEVREUL, MICHEL EUGÈNE, Paris, France (35). 1886. (Born Aug. 31, 1786. Died April 9, 1889.) **C**

GENTH, DR. F. A., 3937 Locust St., Philadelphia, Pa. (24). 1888. **C E**

HALL, PROF. JAMES, Albany, N. Y. (1). 1890. **E F**

FELLOWS.[2]

Abbe, Professor Cleveland, Meteorologist, Weather Bureau, Dept. of Agric., Washington, D. C. (16). 1874. **B A**

Abbott, Dr. Chas. C., Trenton, N. J. (29). 1883. **F H**

Abert, S. Thayer, 1108 G St., N. W., Washington, D. C. (30). 1891. **A B D E I**

Adams, Frank Dawson, McGill Coll., Montreal, P. Q., Can. (29). 1885.

Alden, Prof. Geo. I., Worcester, Mass. (33). 1885. **D**

Alexander, John S., Texas Nat'l Bank, San Antonio, Texas (20). 1874. **B C D**

Allen, Joel A., American Museum of Natural History, Central Park, New York (18). 1875. **F**

Allen, Dr. T. F., 10 E. 36th St., New York, N. Y. (35). 1887. **F**

Alvord, Major Henry E., College Park, Prince George's Co., Md. (29). 1882. **I**

Alwood, Prof Wm. B., Agricultural and Mechanical College and Experiment Station, Blacksburg, Va. (39). 1891. **F**

Ammen, Daniel, Rear Admiral U. S. Navy, Ammendale, Prince George's Co., Md. (26). 1881. **E**

Andrews, Prof. Launcelot W., Iowa City, Iowa (39). 1891. **C**

Anthony, Prof. Wm. A., Manchester, Conn. (28). 1880. **B**

Antisell, Thomas, M.D., 1311 Q St., N. W., Washington, D. C. (33). 1890. **C E**

Arey, Albert L., Free Academy, Rochester, N. Y. (35).

Arthur, J. C., La Fayette, Ind. (21). 1883. **F**

Atkinson, Edward, 31 Milk St., Boston, Mass. (29). 1881. **I D**

Atwater, Prof. W. O., Wesleyan Univ., Middletown, Conn. (29). 1882. **C**

Atwell, Charles B., 1038 Sherman St., Evanston, Ill. (36). 1890. **F**

Auchincloss, Wm. S., 209 Church St., Philadelphia, Pa. (29). 1886. **D A**

Avery, Elroy M., Ph.D., Woodland Hills Ave., Cleveland, Ohio (37). 1889. **B**

Ayres, Prof. Brown, Tulane Univ., New Orleans, La. (31). 1885. **B**

[1] See ARTICLE VI of the Constitution. [2] See ARTICLE IV of the Constitution.

*** The number in parenthesis indicates the meeting at which the member joined the Association; the date following is the year when made a Fellow; the black letters at end of line are those of the sections to which the Fellow belongs.

When the name is given in small capitals, it designates that the Fellow is also a Life Member, and is entitled to the Annual Volume of Proceedings.

Babcock, S. Moulton, Madison, Wis. (33). 1885. **C**

Bailey, E. H. S., Lawrence, Douglas Co., Kan. (25). 1889. **C E**

Bailey, Prof. Liberty H., Ithaca, N. Y. (34). 1887. **F**

Bailey, Prof. Loring W., University of Fredericton, N. B. (18). 1875.

Bailey, Prof. W. W., Brown University, Providence, R. I. (18). 1874. **F**

Baker, Frank, M.D., 1315 Corcoran St., Washington, D. C. (31). 1886. **F H**

Baker, Marcus, U. S. Geological Survey, Washington, D. C. (30). 1882. **A**

Baldwin, Judge Charles C., 1264 Euclid Ave., Cleveland, Ohio (37). 1891. **H I**

Ballard, Harlan H., 50 South St., Pittsfield, Mass. (31). 1891. **E F**

Barker, Prof. G. F., Univ. of Penn., Philadelphia, Pa. (13). 1875. **B C**

Barnard, Edward E., Lick Observ., San José, Cal. (26). 1883. **A**

Barnes, Prof. Chas. R., Madison, Wis. (33). 1885. **F**

Bartlett, Prof. Edwin J., Dartmouth College, Hanover, N. H. (28). 1883. **C**

Bartlett, John R., Commander U. S. N., Lonsdale, R. I. (30). 1882. **E B**

Barus, Carl, Ph.D., U. S. Geol. Survey, Washington, D. C. (33). 1887. **B**

Bassett, Homer F., Waterbury, Conn. (23). 1874. **F**

Bates, Henry H, Ph.D., U. S. Patent Office, Washington, D. C. (33). 1887. **B A C D**

Battle, Herbert B., Ph.D., Director N. C. Agric. Exper. Station, Raleigh, N. C. (33). 1889. **C**

Baur, George, Clark Univ., Worcester, Mass. (36). 1889.

Bausch, Edward, Rochester, N. Y. (26). 1883. **A B C F**

Beal, Prof. Wm. James, Agricultural College, Ingham Co., Mich. (17). 1880. **F**

Beardsley, Prof. Arthur, Swarthmore College, Swarthmore, Del. Co., Pa. (33). 1885. **D**

Beauchamp, Rev. Wm. M., Baldwinsville, N. Y. (34). 1886. **H**

Becker, Dr. Geo. F., U. S. Geol. Survey, Washington, D. C. (36). 1890. **E**

Bell, Dr. Alex. Graham, Scott Circle, 1331 Connecticut Ave., Washington, D. C. (26). 1879. **B H I**

Bell, Alex. Melville, 1525 35th St., Washington, D. C. (31). 1885. **H**

Bell, Robert, M.D., Ass't Director Geological Survey, Ottawa, Ontario, Can. (38). 1889. **E F**

Beman, Wooster W., 19 So. 5th St., Ann Arbor, Mich. (34). 1886. **A**

Benjamin, Marcus, care D. Appleton & Co., New York, N. Y. (27). 1887. **C**

Benjamin, Rev. Raphael, M.A., 178 E. 70th St., New York, N. Y. (34). 1887. **F A B D E H I**

Bennett, Prof. Wm. Z., Wooster, Wayne Co., Ohio (33). 1889. **C**

Bessey, Prof. Charles E., Univ. of Nebraska, Lincoln, Neb. (21). 1880. **F**

Bethune, Rev. C. J. S., Trinity College School, Pt. Hope, Ont., Can. (18). 1875. **F**

Beyer, Dr. Henry G., U. S. N., U. S. National Museum, Washington, D. C. (31). 1884. **F**

Bickmore, Prof. Albert S., American Museum of Natural History, 8th Ave. and 77th St., Central Park, New York, N. Y. (17). 1880. **H**

Bigelow, Prof. Frank H., Naut. Almanac, Washington, D. C. (36). 1888. **A**

Billings, John S., Surgeon U. S. A., Surg. General's Office, Washington, D. C. (32). 1883. **F H**

Blackham, George E., M.D., Dunkirk, N. Y. (25). 1883. **F**

Blake, Clarence J., M.D., 226 Marlborough St., Boston, Mass. (24). 1877. **B F**

Blake, Prof. Eli W., Brown Univ., Providence, R. I. (15). 1874. **B**

Blake, Francis, Auburndale, Mass. (23). 1874. **B A**

Blue, Archibald, Director of the Bureau of Mines, Toronto, Ontario, Can. (35). 1890. **I**

Boardman, Mrs. William D., 38 Kenilworth St., Roxbury, Mass. (28). 1885. **E H**

Boas, Dr. Franz, Clark Univ., Worcester, Mass. (36). 1888. **H**

Boerner, Chas. G., Vevay, Switzerland Co., Ind. (29). 1886. **A B E**

Bolton, Dr. H. Carrington, University Club, New York, N. Y. (17). 1875. **C**

Bond, Geo. M., care of The Pratt & Whitney Co., Hartford, Conn. (33). 1885. **D**

Bourke, John G., Capt. 3d Cavalry, U. S. A., War Dept., Washington, D. C. (33). 1885. **H**

Bouvé, Thos. T., Boston Soc. Nat. Hist., Boston, Mass. (1). 1875. **E**

Bowditch, Prof. H. P., Jamaica Plain, Mass. (28). 1880. **F B H**

Bowser, Prof. E. A., Rutgers College, New Brunswick, N. J. (28). 1881.

Brackett, Prof. C. F., College of New Jersey, Princeton, N. J. (19). 1875. **B**

Brackett, Richard N., Associate Prof. of Chemistry, Clemson Agric. College, Fort Hill, S. C. (37). **C E**

Bradford, Royal B., Commander U. S. N., care Navy Dept, Washington, D. C. (31). 1891. **B D**

Branner, John C., Leland Stanford jr. Univ., Menlo Park, Cal. (34). 1886. **E F**

Brashear, Jno. A., Allegheny, Pa. (33). 1885. **A B D**

Brewer, Prof. Wm. H., New Haven, Conn. (20). 1875. **E F I**

Brewster, William, 61 Sparks St., Cambridge, Mass. (29). 1884. **F**

Brinton, D. G., M.D., Media, Pa. (33). 1885. **H**

Britton, N. L., Columbia College, New York, N. Y. (29). 1882. **F E**

Broadhead, Garland Carr, University, Columbia, Mo. (27). 1879. **E**

Brooks, Wm. R., Box 714, Geneva, N. Y. (35). 1886. **A B D G**

Brown, Robert, care of Yale College Observatory, New Haven, Conn. (11). 1874.

Brown, Mrs. Robert, New Haven, Conn. (17). 1874.

Brühl, Gustav, cor. John and Hopkins Sts., Cincinnati, Ohio (28). 1886. **H**

Brush, Charles F., Brush Electric Light Co., Cleveland, Ohio (35). 1886. **B**

Brush, Prof. George J., Yale College, New Haven, Conn. (4). 1874. **C E**
Bryce, George, LL.D., Manitoba College, Winnipeg, Manitoba (38). 1889. **H**
Buckhout, W. A., State College, Centre Co., Pa. (20). 1881. **F**
Burgess, Dr. Thomas J. W., Med. Sup't, Protestant Hospital for the Insane, Montreal, P.Q., Can. (38). 1889. **F**
Burr, Prof. William H., 151 W. 74th St., New York, N. Y. (31). 1883.
Burrill, Prof. T. J., Univ. of Illinois, Champaign, Ill. (29). 1882. **F**
Butler, A. W., Brookville, Franklin Co., Ind. (30). 1885. **F H**

Caldwell, Prof. Geo. C., Cornell University, Ithaca, N. Y. (23). 1875. **C**
Calvin, Prof. Samuel, State Univ. of Iowa, Iowa City, Iowa (37). 1889. **E F**
Campbell, Prof. Douglas H., Menlo Park, Cal. (34). 1888. **F**
Canby, William M., 1101 Delaware Avenue, Wilmington, Del. (17). 1878. **F**
Carhart, Prof. Henry S., University of Michigan, Ann Arbor, Mich. (29). 1881. **B**
Carpenter, Louis G., Agricultural College, Fort Collins, Col. (32). 1889. **A B**
Carpenter, Capt. W. L., U. S. A., Dunkirk, N. Y. (24). 1877. **F E**
Carpmael, Charles, Director of Magnetic Observatory, Toronto, Ontario, Can. (31). 1883. **B**
Carr, Lucien, Peabody Museum Archæology and Ethnology, Cambridge, Mass. (25). 1877. **H**
Case, Col. Theo. S., Kansas City, Mo. (27). 1883. **H B**
Chamberlain, Alexander F., Clark Univ., Worcester, Mass. (38). 1890. **H**
Chamberlin, T. C., Madison, Wis. (21). 1877. **E B F H**
Chandler, Prof. C. F., School of Mines, Columbia Coll., East 49th St. cor. 4th Ave., New York, N. Y. (19). 1875. **C**
Chandler, Prof. Charles Henry, Ripon, Wis. (28). 1883. **A B**
Chandler, Seth C., jr., 16 Craigie St., Cambridge, Mass. (29). 1882. **A**
Chandler, Prof. W. H., South Bethlehem, Pa. (19). 1874. **C**
Chanute, O., 5 Ritchie Place, Chicago, Ill. (17). 1877. **D I**
Chapin, Dr. J. H., Meriden, Conn. (33). 1886. **E H**
Chester, Prof. Albert H., Rutgers College, New Brunswick, N. J. (29). 1882. **C F**
Chester, Prof. Fred'k D., Del. State Coll., Newark, Del. (33). 1887. **E**
Chickering, Prof. J. W., jr., Deaf Mute College, Washington, D. C. (22). 1877. **F I**
Christie, Alexander Smyth, U. S. C. and G. Survey, Washington, D. C. (39). 1891. **A B D**
Chute, Horatio N., Ann Arbor, Mich. (34). 1889. **B C A**
Clapp, Miss Cornelia M., Mt. Holyoke Seminary, South Hadley, Mass. (31). 1883. **F**
Clark, Alvan G., Cambridgeport, Mass. (28). 1880. **A B**
Clark, Prof. John E., 30 Trumbull St., New Haven, Conn. (17). 1875. **A**
Clark, Wm. Bullock, Ph.D., Johns Hopkins Univ., Baltimore, Md. (37). 1891. **E**

Clarke, Prof. F. W., U. S. Geological Survey, Washington, D. C. (18). 1874. **C**

Claypole, Prof. Edw. W., Buchtel Coll., Akron, Ohio (30). 1882. **E F**

Clayton, H. Helm, Readville, Mass. (34). 1887. **B**

Cloud, John W., 974 Rookery, Chicago, Ill. (28). 1886. **A B D**

Coffin, Prof. Selden J., Lafayette College, Easton, Pa. (22). 1874. **A I**

Cogswell, W. B., Syracuse, N. Y. (33). 1891. **D**

Cole, Prof. Alfred D., Denison Univ., Granville, Ohio (39). 1891. **B C**

Collett, Prof. John, Indianapolis, Ind. (17). 1874. **E**

Collin, Prof. Alonzo, Cornell College, Mount Vernon, Iowa (21). 1891. **B C**

Collingwood, Francis, Elizabeth, N. J. (36). 1888. **D**

Colvin, Verplanck, Supt. N. Y. State Adirondack Survey, Albany, N. Y. (28). 1880. **E**

Comstock, Prof. Geo. C., Washburn Observ., Univ. of Wisconsin, Madison, Wis. (34). 1887. **A**

Comstock, J. Henry, Cornell Univ., Ithaca, N. Y. (28). 1882. **F**

Comstock, Milton L., 641 Academy St., Galesburg, Ill. (21). 1874. **A**

Comstock, Prof. Theo. B., Director School of Mines, Univ. of Arizona, Tucson, Arizona (24). 1877. **D E B**

Cook, Prof. A. J., Agricultural College, Mich. (24). 1880. **F**

Cook, Chas. Sumner, Evanston, Ill. (36). 1889. **B**

Cooley, Prof. Le Roy C., Vassar College, Poughkeepsie, N. Y. (19). 1880. **B C**

Cooley, Prof. Mortimer E., Univ. of Michigan, Ann Arbor, Mich. (33). 1885. **D**

Cope, Prof. Edward D., 2100 Pine St., Philadelphia, Pa. (17). 1875. **F E**

Corthell, Elmer L., "The Temple," Chicago, Ill. (34). 1886. **D**

Coulter, Prof. John M., Wabash College, Crawfordsville, Ind. (32). 1884. **F**

Coulter, Prof. Stanley., La Fayette, Ind. (35). 1890. **F**

Coville, Frederick V., Dept. of Agric., Washington, D. C. (35). 1890. **F**

Cox, Prof. Edward T., Gilsey House, New York, N. Y. (19). 1874. **E**

Cox, Hon. Jacob D., Gilman Ave., Mt. Auburn, Cincinnati, Ohio (30). 1881. **F**

Coxe, Eckley B., Drifton, Luzerne Co., Pa. (23). 1879. **D E**

Cragin, Francis W., 2004 San Antonio St., Austin, Texas (29). 1890. **F E H**

Crampton, Chas. A., M.D., Office of Internal Revenue, Treasury Department, Washington, D.C. (36). 1887. **C**

Crandall, Prof. A. R., Lexington, Ky. (29). 1883. **E F**

Crawford, Prof. Morris B., Middletown, Conn. (30). 1889. **B**

Crosby, Prof. Wm. O., Boston Society of Natural History, Boston, Mass. (29). 1881. **E**

Cross, Prof. Chas. R., Mass. Institute Technology, Boston, Mass. (29). 1880. **B**

Crozier, A. A., Agricultural College, Ames, Iowa (36). 1891. **F**

Culin, Stewart, 127 South Front St., Philadelphia, Pa. (33). 1890. **H**
Cummings, John, Cummingsville, Woburn, Mass. (18). 1890. **F**
Cushing, Henry Platt, 786 Prospect St., Cleveland, Ohio (33). 1888. **E**
Cutting, Hiram A., M.D., State Geologist, Lunenburgh, Vt. (17). 1874. **E F**

Dall, William H., Smithsonian Institution, Washington, D. C. (18). 1874. **H F**
Dana, Edward Salisbury, New Haven, Conn. (23). 1875. **B E**
Dana, Prof. James D., New Haven, Conn. (1). 1875. **E**
Dancy, Frank B., A.B., Analytical and Consulting Chemist, Office and Laboratory, 133½ Fayetteville St., Raleigh, N. C. (33). 1890. **C**
Davidson, Prof. Geo., U. S. Coast and Geodetic Survey, San Francisco, Cal. (29). 1881. **A B D**
Davis, Wm. Morris, Cambridge, Mass. (33). 1885. **E B**
Dawson, Sir William, Principal McGill College, Montreal, Can. (10). 1875. **E**
Day, David F., Buffalo, N. Y. (35). 1887. **F**
Day, Fisk H., M.D., Wauwatosa, Wis. (20). 1874. **E H F**
Dean, George W., P. O. Box 92, Fall River, Mass. (15). 1874. **A**
Denton, Prof. James E., Stevens Institute, Hoboken, N. J. (36). 1888. **D B A**
Derby, Orville A., San Paulo, Brazil, S. A. (39). 1890.
Dewey, Fred P., Ph.B., 621 F St. N. W., Washington, D. C. (30). 1886. **C E**
Dimmock, George, P. O. Box 15, Canobie Lake, N. H. (22). 1874. **F**
Dodge, Charles R., 1336 Vermont Ave., Washington, D. C. (22). 1874.
Dodge, Prof. James A., University of Minnesota, Minneapolis, Minn. (29). 1884. **C E**
Dodge, J. Richards, Washington, D. C. (31). 1884. **I H**
Dolbear, A. Emerson, College Hill, Mass. (20). 1880. **B**
Doolittle, Prof. C. L., South Bethlehem, Pa. (25). 1885. **A**
Dorsey, Rev. J. Owen, Box 78, Tacoma Park, , D. C. (31). 1883. **H**
Douglass, Andrew E., 63 Pine St., New York, N. Y. (31). 1885. **H**
Dow, Capt. John M., 83 W. 71st St., New York, N. Y. (31). 1884. **F H**
Draper, Dan'l, Ph.D., Director N. Y. Meteorological Observatory, Central Park, 64th St., Fifth Avenue, New York, N. Y. (29). 1881. **B D F A**
Drown, Prof. Thos. M., Mass. Institute Technology, Boston, Mass. (29). 1881. **C**
Du Bois, Prof. Aug. J., New Haven, Conn. (30). 1882. **A B D**
Du Bois, Patterson, Ass't Editor S.S.T., 1031 Walnut St., Philadelphia, Pa. (33). 1887. **H C I**
Dudley, Charles B., Altoona, Pa. (23). 1882. **C B D**
Dudley, P. H., 66½ Pine St., New York, N. Y. (29). 1884.
Dudley, Wm. L., Prof. of Chemistry, Vanderbilt Univ., Nashville, Tenn. (28). 1881. **C**

Dudley, Prof. Wm. R., Cornell Univ., Ithaca, N. Y. (29). 1883. **F**
Dumble, E. T., Austin, Texas (37). 1891. **E**
Dunham, Edw. K., 53 E. 30th St., New York, N. Y. (30). 1890.
Dunnington, Prof. F. P., University Station, Charlottesville, Va. (26). 1880. **C**
Durand, Prof. W. F., Ph.D., Agricultural College, Mich. (37). 1890. **B**
Dwight, Prof. William B., Vassar College, Poughkeepsie, N. Y. (30). 1882. **E F**

Eastman, Prof. J. R., U. S. Naval Observatory, Washington, D. C. (26). 1879. **A**
Eaton, Prof. D. G., 55 Pineapple St., Brooklyn, N. Y. (19). 1874. **B E**
Eaton, Prof. James R., Liberty, Mo. (29). 1885. **C B E**
Eddy, Prof. H. T., Rose Polytechnic Inst., Terre Haute, Ind. (24). 1875. **A B D**
Edison, Thos. A., Orange, N. J. (27). 1878. **B**
Edmands, J. Rayner, Observatory, Cambridge, Mass. (29). 1880.
Egleston, Prof. Thomas, 35 W. Washington Square, New York, N. Y. (27). 1879. **C D E**
Eimbeck, William, U. S. C. and G. Survey, Washington, D. C. (17). 1874. **A B D**
Eldridge, Geo. H., care U. S. Geol. Survey, Washington, D. C. (37). 1890. **E**
Elkin, William L., Yale Coll. Observ., New Haven, Conn. (33). 1885. **A**
Ely, Theo. N., Sup't Motive Power, Penn. R. R., Altoona, Pa. (29). 1886.
Emerson, Prof. Benjamin K., Amherst, Mass. (19). 1877. **E F**
Emery, Albert H., Stamford, Conn. (29). 1884. **D B**
Emery, Charles E., Bennett Building, New York, N. Y. (34). 1886. **D B A**
Emmons, S. F., U. S. Geol. Survey, Washington, D. C. (26). 1879. **E**
Engelmann, George J., M.D., 3003 Locust St., St. Louis, Mo. (25). 1875. **F H**
Ernst, Carl W., Room 76, Post Office, Boston, Mass. (23). 1874. **I H**
Evermann, Prof. Barton W., U. S. Fish Commission, Washington, D. C. (39). 1891.
Ewing, Thomas, jr., Patent Office, Washington, D. C. (36). 1889. **B**
Eyerman, John, Easton, Pa. (33). 1889. **E C**

Fairbanks, Henry, Ph.D., St. Johnsbury, Vt. (14). 1874. **B D A**
Fairchild, Prof. H. L., University of Rochester, Rochester, N. Y. (28). 1883. **E F**
Fanning, John T., Consulting Eng., Kasota Block, Minneapolis, Minn. (29). 1885. **D**
Farlow, Dr. W. G., 29 Holyoke House, Cambridge, Mass. (20). 1875. **F**
Farmer, Moses G., Eliot, Me. (9). 1875.
Farquhar, Henry, Coast Survey Office, Washington, D. C. (33). 1886. **A I F B**
Fernald, Prof. Charles H., Amherst, Mass. (22). 1881. **F E**

Fernald, Prof. M. C., State Agric. College, Orono, Me. (22). 1883. **B A**
Fernow, Bernhard E., Chief of Forestry Division, Dep't of Agriculture, Washington, D. C. (31). 1887. **F I**
Firmstone, F., Easton, Pa. (33). 1887. **D**
Fiske, Thos. S., A.M., Ph.D., Columbia College, New York, N. Y. (38). 1891. **A**
Fitch, Edward H., Jefferson, Ashtabula Co., Ohio (11). 1874. **I E**
Fletcher, Miss Alice C., care Peabody Museum, Cambridge, Mass. (29). 1883. **H**
Fletcher, James, Dominion Entomologist, Ottawa, Ontario, Can. (31). 1883. **F**
Fletcher, Dr. Robert, Army Medical Museum, Washington, D. C. (29). 1881. **F H**
Flint, Albert S., Washburn Observ., Madison, Wis. (30). 1887. **A**
Flint, James M., Surgeon U. S. N., Smithsonian Institution, Washington, D. C. (28). 1882. **F**
Foote, Dr. A. E., 4116 Elm Ave., Philadelphia, Pa. (21). 1874. **E C**
Forbes, Prof. S. A., Univ. of Illinois, Champaign, Ill. (27). 1879. **F**
Fox, Oscar C., U. S. Patent Office, Washington, D. C. (36). 1891. **B D**
Foye, Prof. J. C., Lawrence Univ., Appleton, Wis. (29). 1884. **C B**
Frazer, Dr. Persifor, Drexel Building, Room 1042, Philadelphia, Pa. (24). 1879. **E C**
Frazier, Prof. B. W., The Lehigh University, So. Bethlehem, Pa. (24). 1882. **E C**
Frear, Wm., State College, Centre Co., Pa. (33). 1886. **C**
Freer, Prof. Paul C., Ann Arbor, Mich. (39). 1891. **C**
French, Prof. Thomas, jr., Ridgeway Ave., Avondale, Cincinnati, Ohio (30). 1883. **B**
Frisby, Prof. Edgar, U. S. N. Observ., Washington, D. C. (28). 1880. **A**
Frost, Edwin Brant, Hanover, N. H. (38). 1890. **A B**
Fuller, Andrew S., Ridgewood, Bergen Co., N. J. (24). 1882. **F**
Fuller, Prof. Homer T., Polytechnic Inst., Worcester, Mass. (35). 1891. **C E**
Fulton, Prof. Robert B., University, Miss. (21). 1887. **B A**

Gaffield, Thomas, 54 Allen St., Boston, Mass. (29). 1889. **C B**
Gage, Simon Henry, Ithaca, N. Y. (28). 1881. **F**
Galbraith, Prof. John, Toronto, Ontario, Can. (38). 1889.
Galloway, B. T., Dep't of Agriculture, Washington, D. C. (37). 1890. **F**
Gannett, Henry, U. S. Geological Survey, Washington, D. C. (33). 1884. **E I A**
Gardiner, Dr. Edward G., Massachusetts Institute Technology, Boston, Mass. (29). 1890. **F**
Garland, Rev. Dr. L. C., Chancellor Vanderbilt University, Nashville, Tenn. (25). 1877 **B**
Garman, Samuel, Museum Comparative Zoology, Cambridge, Mass. (20). 1874. **F E**

Gatschet, Dr. Albert S., Box 333, Washington, D. C. (30). 1882. **H**
Gibbs, Prof. J. Willard, New Haven, Conn. (33). 1885. **B**
Gilbert, G. K., U. S. Geological Survey, Washington, D. C. (18). 1874. **E**
Gill, Prof. Theo., Smithsonian Inst., Washington, D. C. (17). 1874. **F**
Gilman, Daniel C., President Johns Hopkins University, Baltimore, Md. (10). 1875. **E H**
Goessman, Prof. C. A., Mass. Agricultural College, Amherst, Mass. (18). 1875. **C**
Goff, E. S., Madison, Wis. (35). 1889.
Gold, Theodore S., West Cornwall, Conn. (4). 1887. **B C**
Goldschmidt, S. A., Ph.D., 43 Sedgwick St., Brooklyn, N. Y. (24). 1880. **C E B**
Gooch, Frank A., Yale College, New Haven, Conn. (25). 1880. **C**
Goodale, Prof. G. L., Botanic Gardens, Cambridge, Mass. (18). 1875.
Goode, G. Brown, Curator Nat'l Museum, Washington, D. C. (22). 1874.
Goodfellow, Edward, Ass't U. S. Coast and Geodetic Survey, Washington, D. C. (24). 1879. **A H**
Gould, Dr. B. A., Cambridge, Mass. (2). 1875. **A B**
Grant, Mrs. Mary J., Brookfield, Conn. (23). 1874. **A**
Gratacap, L. P., Ph.B., 77th St. and 8th Ave., New York, N. Y. (27). 1884. **C E F**
Gray, Elisha, Sc.D., Highland Park, Ill. (32). 1883. **B**
Gray, Prof. Thomas, Terre Haute, Ind. (38). 1889.
Green, Arthur L., La Fayette, Ind. (33). 1888. **C**
Green, Traill, M.D., Easton, Pa. (1). 1874. **C F**
Grinnell, George Bird, 40 Park Row, New York, N. Y. (25). 1885. **F E**
Gulley, Prof. Frank A., College Station, Texas (30). 1883.

Hagen, Dr. Hermann A., Museum Comparative Zoology, Cambridge, Mass. (17). 1875. **F**
Hague, Arnold, U. S. Geol. Survey, Washington, D. C. (26). 1879.
Haines, Reuben, Haines and Chew St., Germantown, Philadelphia, Pa. (27). 1889. **C B**
Hale, Albert C., Ph.D., No. 551 Putnam Ave., Brooklyn, N. Y. (29). 1886. **C B**
Hale, Geo. E., 4545 Drexel Ave., Chicago, Ill. (37). 1891. **A B C**
Hale, Horatio, Clinton, Ontario, Can. (30). 1882. **H**
Hall, Prof. Asaph, U. S. Naval Observatory, Washington, D. C. (25). 1877. **A**
Hall, Asaph, jr., U. S. Naval Observ., Washington, D. C. (38). 1890. **A**
Hall, Prof. C. W., 803 Univ. Ave. So., Minneapolis, Minn. (28). 1883. **E**
Hall, Prof. Edwin H., 5 Avon St., Cambridge, Mass. (29). 1881. **B**
Hall, Prof. Lyman B., Haverford College, Pa. (31). 1884. **C**
Hallowell, Miss Susan M., Wellesley Coll., Wellesley, Mass. (33). 1890. **F**
Halsted, Byron D., New Jersey Agricultural Experiment Station, New Brunswick, N. J. (29). 1883. **F**
Hambach, Dr. G., 1319 Lami St., St. Louis, Mo. (26). 1891. **F E**
Hamlin, Dr. A. C., Bangor, Me. (10). 1874. **C E H**
Hanaman, C. E., Troy, N. Y. (19). 1883. **F**

Hardy, Prof. A. S., Dartmouth College, Hanover, N. H. (28). 1883. **A**

Harkness, Prof. William, U. S. N. Observatory, Washington, D. C. (26). 1878. **A B C D**

Harrington, H. H., College Station, Texas (35). 1889. **C**

Harris, Uriah R., Lieutenant U. S. N., U. S. Naval Acad., Annapolis, Md. (34). 1886. **A**

Harris, W. T., Lock Box 1, Concord, Mass. (27). 1887. **H I**

Hart, Edw., Ph.D., Easton, Pa. (33). 1885. **C**

Hasbrouck, Prof. I. E., 364 Carlton Ave., Brooklyn, N. Y. (23). 1874. **D A I**

Hastings, C. S., Sheffield Scientific School of Yale College, New Haven, Conn. (25). 1878. **B**

Haupt, Prof. Lewis M., University of Pennsylvania, Philadelphia, Pa. (32). 1885. **I D E**

Haworth, Prof. Erasmus, Pennsylvania College, Oskaloosa, Iowa (37). 1890. **E**

Hay, Prof. O. P., Irvington, Ind. (37). 1889. **E F**

Haynes, Henry W., 239 Beacon St., Boston, Mass. (28). 1884. **H**

Heal, Wm. E., Marion, Ind. (39). 1891. **A**

Heilprin, Prof. Angelo, Acad. Nat. Sciences, Philadelphia, Pa. (33). 1885. **E F**

Heitzmann, Dr. Charles, 39 W. 45th St., New York, N. Y. (36). 1890.

Hendricks, J. E., Des Moines, Iowa (29). 1885. **A**

Henshaw, Henry W., Bureau of Ethnology, Washington, D. C. (24). 1877. **H**

Hering, Rudolph, Civil and Sanitary Engineer, 277 Pearl St., New York, N. Y. (33). 1885. **D E I**

Herrick, Clarence L., 12 Mason St., Mt. Auburn, Cincinnati, Ohio (31). 1884. **F E**

Hervey, Rev. A. B., President St. Lawrence University, Canton, N.Y. (22). 1879. **F**

Hicks, Prof. Lewis E., State University, Lincoln, Neb. (31). 1885. **E F**

Hilgard, Prof. E. W., University of California, Berkeley, Cal. (11). 1874. **C E B**

Hill, Chas. S., care Dep't of State, Washington, D. C. (33). 1887. **A I**

Hill, Robert Thomas, Univ. of Texas, Austin, Texas (36). 1889. **E**

Himes, Prof. Charles F., Carlisle, Pa. (29). 1882. **B C**

Hinrichs, Dr. Gustavus, 3132 Lafayette Ave., St. Louis, Mo. (17). 1874.

Hirschfelder, Chas. A., Vice Consul U. S. A., Toronto, Ontario, Can. (33). 1887. **H**

Hitchcock, Prof. Charles H., Hanover, N. H. (11). 1874. **E**

Hitchcock, Romyn, Washington, D. C. (29). 1881. **C B**

Hoffmann, Dr. Fred., "Rundschau," P. O. Box 1680, New York, N. Y. (28). 1881. **C F**

Holden, Prof. E. S., Lick Observatory, San José, Cal. (23). 1875. **A**

Holman, Silas W., Massachusetts Institute of Technology, Boston, Mass. (31). 1883. **B**

Holmes, Prof. Jos. A., Chapel Hill, N. C. (33). 1887. **E F**

Holmes, Dr. Oliver Wendell, 296 Beacon St., Boston, Mass. (29). 1881. **H**
Holmes, Wm. H., Bureau of Ethnology, Smithsonian Institution, Washington, D. C. (30). 1883. **H**
Holway, E. W. D., Decorah, Iowa (33). 1890. **F**
Horsford, Prof. E. N., Cambridge, Mass. (1). 1876. **C E**
Horton, S. Dana, Pomeroy, Ohio (37). 1889. **I**
Hosea, Lewis M., Johnston Building, Cincinnati, Ohio (30). 1883. **B H**
Hotchkiss, Major Jed., Staunton, Va. (31). 1883. **E H I**
Hough, Prof. G. W., Director Dearborn Observatory, Evanston, Ill. (15). 1874. **A**
Hough, Walter, U. S. National Museum, Washington, D. C. (38). 1890.
Hovey, Rev. Horace C., 14 Park St., Bridgeport, Conn. (29). 1883. **E H**
Howard, Leland O., Dep't of Agric., Washington, D. C. (37). 1889. **F**
Howe, Charles S., Prof. of Mathematics, Case School of Applied Science, Cleveland, Ohio (34). 1891. **A**
Howe, Jas. Lewis, Louisville, Ky. (36). 1888. **C**
Howell, Edwin E., 537 15th St., N. W., Washington, D. C. (25), 1891. **E**
Hoy, Philo R., M.D., 902 Main St., Racine, Wis. (17). 1875. **F H**
Hulst, Rev. Geo. D., 15 Himrod St., Brooklyn, N. Y. (29). 1887. **F**
Hunt, Alfred E., 116 Water St., Pittsburgh, Pa. (35). 1891. **C D**
Hunt, George, 119 Prospect St., Providence, R. I. (9). 1874.
Hyatt, Prof. Alpheus, Natural History Society, Boston, Mass. (18). 1875. **E**
Hyde, Prof. E. W., Station D, Cincinnati, Ohio (25). 1881. **A**

Iddings, Joseph P., U. S. Geological Survey, Washington, D. C. (31). 1884. **E**
Irby, Prof. B., Irby, Ga. (37). 1891. **F**

Jack, John G., Jamaica Plain, Mass. (31). 1890. **F**
Jackson, Robert T., 33 Gloucester St., Boston, Mass. (37). 1890. **F**
Jacobus, David S., Stevens Institute, Hoboken, N. J. (36). 1889. **D B A**
Jacoby, Harold, Columbia College, New York, N. Y. (38). 1891. **A**
James Edmund J., Ph.D., Univ. of Penn., Philadelphia, Pa. (33). 1887. **I**
James, Jos. F., M.S., U. S. Geol. Survey, Washington, D. C. (30). 1882. **F E**
Jastrow, Dr. Jos., Univ. of Wisconsin, Madison, Wis. (35). 1887. **H F**
Jayne, Horace F., 1826 Chestnut St., Philadelphia, Pa. (29). 1884. **F H**
Jeffries, B. Joy, M.D., 15 Chestnut St., Boston, Mass. (29). 1881. **F H**
Jenkins, Edw. H., New Haven, Conn. (33). 1885. **C**
Jenkins, Prof. Oliver P., Leland Stanford jr. Univ., Menlo Park, Cal. (39). 1891. **F**
Jenks, Elisha T., Middleborough, Mass. (22). 1874. **D**
Jenks, Prof. J. W. P., Middleborough, Mass. (2). 1874. **B**
Jesup, Prof. Henry G., Dartmouth College, Hanover, N. H. (36). 1891. **F**
Jesup, Morris K., 52 William St., New York, N. Y. (29). 1891. **I**
Jewell, Theo. F., Commander U. S. Navy, Naval Torpedo Station, Newport, R. I. (25). 1882. **B**

Jillson, Dr. B. C., 6224 Station St., E.E., Pittsburgh, Pa. (14). 1881. **E H F**
Johnson, John B., Washington Univ., St. Louis, Mo. (33). 1886. **D**
Johnson, Lawrence C., U. S. Geol. Survey, Gainesville, Fla. (33). 1887.
Johnson, Otis C., 52 Thayer St., Ann Arbor, Mich. (34). 1886. **C**
Johnson, Prof. W. W., Naval Academy, Annapolis, Md. (29). 1881. **A**
Jordan, Prof. David S., Palo Alto, Menlo Park P. O., Cal. (31). 1883. **F**
Julien, A. A., New York Acad. of Sciences, New York, N. Y. (24). 1875. **E C**

Kedzie, Mrs. Nellie S., Manhattan, Kan. (34). 1890. **I F**
Kedzie, Prof. Robert C., Agricultural College, Mich. (29). 1881. **C**
Kellicott, David S., Columbus, Ohio (31). 1883. **F**
Kemp, James F., School of Mines, Columbia College, New York, N. Y. (36). 1888. **E**
Kendall, Prof. E. Otis, 3826 Locust St., Philadelphia, Pa. (29). 1882. **A**
Kent, William, Passaic, N. J. (26). 1881. **D I**
Kershner, Prof. Jefferson E., Lancaster City, Pa. (29). 1883. **A B**
Keyes, Charles R., 926 Ninth St., Des Moines, Iowa (37). 1890.
Kinealy, John H., No. Caro. College of Agric. and Mechan. Arts, Raleigh, N. C. (36). 1891. **D**
Kinnicutt, Dr. Leonard P., Polytechnic Inst., Worcester, Mass. (28). 1883. **C**
Kirkwood, Prof. Daniel, Arlington Ave., Riverside, Cal. (7). 1874. **A**
Klotz, Otto Julius, Preston, Ontario, Can. (38). 1889.
Kunz, G. F., 402 Garden St., Hoboken, N. J. (29). 1883. **E H C**

Ladd, Prof.E. F., Agric. College, Fargo, No. Dakota (36). 1889. **C**
Laflamme, Prof. J. C. K., Laval Univ., Quebec, Can. (29). 1887. **E B**
LaFlesche, Francis, Indian Bureau, Interior Dep't, Washington, D. C. (33). 1885. **H**
Lambert, Rev. Thomas R., D.D., Hotel Oxford, Huntington Ave., Boston, Mass. (18). 1874.
Landreth, Prof. Olin H., Vanderbilt Univ., Nashville, Tenn. (28). 1883. **D**
Langdon, Dr. F. W., 65 West 7th St., Cincinnati, Ohio (30). 1882. **F H**
Langley, Prof. J. W., 136 First Ave., Pittsburgh, Pa. (23). 1875. **C B**
Langley, Prof. S. P., Secretary Smithsonian Institution, Washington, D. C. (18). 1874. **A B**
Lanza, Prof. Gaetano, Mass. Institute of Technology, Boston, Mass. (29). 1882. **D A B**
Larkin, Edgar L., Director Knox College Observatory, Galesburg, Ill. (28). 1883. **A**
Lattimore, Prof. S. A., University of Rochester, Rochester, N. Y. (15). 1874. **C**
Laudy, Louis H., Ph.D., School of Mines, Columbia College, New York, N. Y. (28). 1890. **C**
Lawrence, George N., 45 E. 21st St., New York, N. Y. (7). 1877. **F**

Lazenby, Prof. Wm. R., Columbus, Ohio (30). 1882. **B I**

Leavenworth, Francis P., Haverford College P. O., Montgomery Co., Pa. (30). 1888. **A**

LeConte, Prof. Joseph, Univ. of Cal., Berkeley, Cal. (29). 1881. **E F**

Ledoux, Albert R., Ph.D., 39 W. 50th St., New York, N. Y. (26). 1881. **C**

Leeds, Prof. Albert R., Stevens Institute, Hoboken, N. J. (23). 1874. **C F**

Lehmann, G. W., Ph.D., 111 S. Gay St., Baltimore, Md. (30). 1885. **C B**

Lesley, Prof. J. Peter, State Geologist of Pennsylvania, 1008 Clinton St., Philadelphia, Pa. (2). 1874. **E**

Leverett, Frank, 4103 Grand Boulevard, Chicago, Ill. (37). 1891. **E**

Libbey, Prof. William, jr., Princeton, N. J. (29). 1887. **E F**

Lilly, Gen. Wm., Mauch Chunk, Carbon Co., Pa. (28). 1882. (Patron) **F E**

Lindenthal, Gustav, C.E., Lewis Block, Pittsburgh, Pa. (37). 1891. **I**

Lindsley, J. Berrien, M.D., 135 North Spruce St., Nashville, Tenn. (1). 1874. **F**

Lintner, J. A., N. Y. State Entomologist, Room 27, Capitol, Albany, N. Y. (22). 1874. **F**

Lloyd, John Uri, Pharmaceutical Chemist, Court and Plum Sts., Cincinnati, Ohio (38). 1890. **C F**

Lloyd, Mrs. Rachel, Box 675, Lincoln, Neb. (31). 1889. **C**

Lockwood, Samuel, Ph.D., Freehold, Monmouth Co., N. J. (18). 1875. **F B A**

Locy, Prof. Wm. A., Lake Forest, Ill. (34). 1890. **F**

Loeb, Morris, Ph.D., Clark Univ., Worcester, Mass. (36). 1889. **C**

Lord, Prof. Nat. W., State Univ., Columbus, Ohio (29). 1881. **C**

Loud, Prof. Frank H., 1203 N. Tejon St., Colorado Springs, Col. (29). **A B**

Loudon, Prof. James, Toronto, Ontario, Can. (25). 1881. **B A**

Loughridge, Dr. R. H., Ass't Prof. Agric. Chem. and Agric. Geol., Univ. of California, Berkeley, Cal. (21). 1874. **E C**

Love, Edward G., School of Mines, Columbia College, New York, N. Y. (24). 1882. **C**

Low, Seth, Pres. Columbia Coll., New York, N. Y. (29). 1890.

Lupton, Prof. N. T., Auburn, Lee Co., Ala. (17). 1874. **C**

Lyon, Dr. Henry, 34 Monument Sq., Charlestown, Mass. (18). 1874.

McBride, Prof. Thomas H., Iowa City, Iowa (38). 1890. **F**

McCauley, Capt. C. A. H., Ass't Q. M., U. S. A., 321 Michigan Ave., Chicago, Ill. (29). 1881.

McCreath, Andrew S., 223 Market St., Harrisburg, Pa. (33). 1889. **C E**

McGee, W. J., U. S. Geol. Survey, Washington, D. C. (27). 1882. **E**

McGill, John T., Ph.D., Vanderbilt Univ., Nashville, Tenn. (36). 1888. **C**

McGuire, Joseph D., Ellicott City, Md. (30). 1891. **H**

McLeod, Prof. C. H., McGill Univ., Montreal, P. Q., Can. (35). 1887. **A B D**

McMahon, James, Ithaca, N. Y. (36). 1891. **A**
McMurtrie, William, care New York Tartar Co., 63 William St., New York, N. Y. (22). 1874. **C**
McNeill, Malcolm, Lake Forest, Ill. (32). 1885. **A**
McRae, Austin Lee, Rolla, Mo. (39). 1891. **B**
Mabery, Prof. C. F., Case School of Applied Science, Cleveland, Ohio. (29). 1881. **C**
Macfarlane, Prof. A., Univ. of Texas, Austin, Texas (34). 1886. **B A**
Macloskie, Prof. George, College of New Jersey, Princeton, N. J. (25). 1882. **F**
Magie, Prof. William F., College of New Jersey, Princeton, N. J. (35). 1887.
Mallery, Col. Garrick, U. S. Army, Bureau of Ethnology, Washington, D. C. (26). 1879. **H**
Mann, B. Pickman, 1918 Sunderland Place, Washington, D. C. (22). 1874. **I F**
Marcy, Oliver, LL.D., Evanston, Ill. (10). 1874. **E**
Marsh, Prof. O. C., Yale College, New Haven, Conn. (15). 1874. **F H**
Martin, Artemas, U. S. Coast Survey, Washington, D. C. (38). 1890. **A**
Martin, Prof. Daniel S., 236 West 4th St., New York, N. Y. (23). 1879. **E F**
Martin, Prof. H. Newell, Johns Hopkins University, Baltimore, Md. (27). 1880. **F H**
Martin, Miss Lillie J., Girls' High School, San Francisco, Cal. (32). 1886. **F C**
Martin, Prof. Wm. J., Davidson College, N. C. (31). 1884. **C E**
Martindale, Isaac C., Camden, N. J. (26). 1890. **F**
Mason, Prof. Otis T., Nat'l Museum, Washington, D. C. (25). 1877. **H**
Mason, Dr. William P., Prof. Rensselaer Polytechnic Inst., Troy, N. Y. (31). 1886. **C**
Matthews, Dr. Washington, 1262 New Hampshire Ave., cor. 21st St., N. W., Washington, D. C. (37). 1888. **H**
Maxwell, Rev. Geo. M., Wyoming, Hamilton Co., Ohio (30). 1886. **H E**
Mayer, Prof. A. M., Stevens Inst. of Technology, Hoboken, N. J. (19). 1874.
Meehan, Thomas, Germantown, Pa. (17). 1875. **F**
Mees, Prof. Carl Leo, Columbus, Ohio (24). 1876. **B C**
Mendenhall, Prof. T. C., U. S. C. and G. Survey, Washington, D. C. (20). 1874. **B**
Menocal, Aricito G., C.E., U. S. N., Navy Yard, Washington, D. C. (36). 1888. **D**
Merrill, Frederick J. H., Ph B., Ass't Director, New York State Museum, Albany, N. Y. (35). 1887. **E**
Merriman, C. C., 1910 Surf St., Lake View, Chicago, Ill. (29). 1880. **F**
Merriman, Prof. Mansfield, So. Bethlehem, Pa. (32). 1885. **A D**
Merritt, Ernest, Ithaca, N. Y. (33). 1890.
Metz, Charles L., M.D., Madisonville, Hamilton Co., Ohio (30). 1885. **H**

Michael, Mrs. Helen Abbott, Torwood, Bonchurch, Isle of Wight, England (33). 1885. **C F**

Michelson, A. A., Master U. S. N., 7 Rockwell St., Cleveland, Ohio (26). 1879. **B**

Miles, Prof. Manly, Lansing, Mich. (29). 1890. **F**

Mills, T. Wesley, Montreal, P. Q., Can. (31). 1886. **F H**

Minot, Dr. Charles Sedgwick, Harvard Medical School, Back Bay, Boston, Mass. (28). 1880. **F**

Minot, Francis, M.D., 65 Marlborough St., Boston, Mass. (29). 1884.

Mixter, Prof. Wm. G., New Haven, Conn. (30). 1882. **C**

Mooney, James, Bureau of Ethnology, Washington, D. C. (38). 1890. **H**

Moore, Eliakim H., Associate Prof. of Math., Northwestern Univ., Evanston, Ill. (39). 1891. **A**

Moore, Prof. J. W., M.D., Lafayette College, Easton, Pa. (22). 1874. **B D A**

Moorehead, Warren K., Xenia, Ohio (38). 1890. **H**

Morley, Prof. Edward W., 749 Republic St., Cleveland, Ohio (18). 1876. **C B E**

Morse, Prof. E. S., Salem, Mass. (18). 1874. **F H**

Morton, H., Stevens Institute Technology, Hoboken, N. J. (18). 1875. **B C**

Moser, Lieut. Jeff. F., U. S. N., Slatington, Lehigh Co., Pa. (28). 1889. **E**

Moses, Prof. Thomas F., Urbana University, Urbana, Ohio (25). 1883. **H F**

Munroe, Prof. C. E., Chemist to Bureau of Ordnance, U. S. Torpedo Station, Newport, R. I. (22). 1874. **C**

Murdoch, John, Rock, Plymouth Co., Mass. (29). 1886. **F H**

Murtfeldt, Miss Mary E., Kirkwood, Mo. (27). 1881. **F**

Myers, John A., Agric. Exper. Station, Morgantown, W. Va. (30). 1889. **C**

Nason, Frank L., 5 Union St., New Brunswick, N. J. (36). 1888. **E**

Nason, Prof. H. B., Rensselaer Polytechnic Institute, Troy, N. Y. (13). 1874. **C E**

Nef, J. U., Clark Univ., Worcester, Mass. (39). 1891. **C**

Nelson, Prof. A. B., Centre College, Danville, Ky. (30). 1882. **A B D**

Newberry, Prof. J. S., Columbia College, New York, N. Y. (5). 1875. **E F H I**

Newberry, Prof. Spencer Baird, Ithaca, N. Y. (33). 1887. **C**

Newcomb, Prof. S., Navy Dep't, Washington, D. C. (13). 1874. **A B**

Newton, Hubert A., New Haven, Conn. (6). 1874. **A**

Nichols, E. L., Ph.D., Cornell Univ., Ithaca, N. Y. (28). 1881. **B C**

Nicholson, Prof. H. H., Box 675, Lincoln, Neb. (36). 1888.

Niles, Prof. W. H., Cambridge, Mass. (16). 1874.

Nipher, Prof. F. E., Washington Univ., St. Louis, Mo. (24). 1876. **B**

Nolan, Edw. J., M.D., Academy of Natural Sciences, Philadelphia, Pa. (29). 1890. **F**

Norton, Lewis M., Ph.D., Mass. Institute of Technology, Boston, Mass. (29). 1884. **C**

Norton, Prof. Thomas H., Univ. of Cincinnati, Cincinnati, Ohio (35). 1887. **C**

Novy, Dr. Frederick G., University of Mich., Ann Arbor, Mich. (36). 1889. **C**

Noyes, Prof. Wm. A., Rose Polytechnic Inst., Terre Haute, Ind. (32). 1885. **C**

Nuttall, Mrs. Zelia, care Peabody Museum, Cambridge, Mass. (35). 1887. **H**

Ogden, Herbert G., U. S. C. and G. Survey, Washington, D. C. (38). 1891. **E**

Oliver, Charles A., M.D., 1507 Locust St., Philadelphia, Pa. (33). 1886. **F H B**

Oliver, Prof. James E., P. O. Box 1566, Ithaca, N. Y. (7). 1875. **A B I**

Ordway, Prof. John M., Tulane University, New Orleans, La. (9). 1875. **C**

Orton, Prof. Edward, President Ohio Agricultural and Mechanical College, Columbus, Ohio (19). 1875. **E**

Osborn, Henry F., Columbia College, New York, N. Y. (29). 1883.

Osborn, Herbert, Ames, Iowa (32). 1884. **F**

Osmond, Prof. I. Thornton, State College, Centre Co., Pa. (33). 1889. **B A C**

Packard, Dr. A. S., 115 Angell St., Providence, R. I. (16). 1875. **F E**

Paine, Cyrus F., 305 Ellwanger & Barry Building, Rochester, N. Y. (12). 1874. **B A**

Paine, Nathaniel, Worcester, Mass. (18). 1874. **H**

Palfray, Hon. Charles W., Salem, Mass. (21). 1874.

Palmer, Chase, Ph.D., Missouri School of Mines, Rolla, Mo. (38). 1889. **C**

Parke, John G., Gen. U. S. A., 16 Lafayette Square, Washington, D. C. (29). 1881. **D**

Parkhurst, Henry M., 173 Gates Ave., Brooklyn, N. Y. (23). 1874. **A**

Patrick, Geo. E., Ames, Iowa (36). 1890. **C**

Patterson, Harry J., College Park P. O., Md. (36). 1890. **C**

Paul, Prof. Henry M., U. S. Naval Observatory, Washington, D. C. (33). 1885. **A B**

Peabody, Selim H., 608 Rand McNally Building, Chicago, Ill. (17). 1885. **D B F**

Peckham, S. F., 159 Olney St., Providence, R. I. (18). 1875. **C B E**

Pedrick, Wm. R., Lawrence, Mass. (22). 1875.

Peet, Rev. Stephen D., Mendon, Ill. (24). 1881. **H**

Pengra, Charles P., M.D., 130 Dartmouth St., Boston, Mass. (34). 1887. **F C**

Penrose, Dr. R. A. F., State Geol. Surv., Little Rock, Ark. (38). 1890. **E**

Perkins, Prof. George H., Burlington, Vt. (17). 1882. **H F E**
Peter, Alfred M., 171 Rose St., Lexington, Ky. (29). 1890. **C**
Peter, Dr. Robert, Kentucky Geol. Survey, Lexington, Ky. (29). 1881. **C**
Peters, Edw. T., P. O. Box 265, Washington, D. C. (33). 1889. **I**
Pettee, Prof. William H., Ann Arbor, Mich. (24). 1875. **E**
Phillips, Prof. A. W., New Haven, Conn. (24). 1879.
Phillips, Prof. Francis C., 59 Sherman Ave., Allegheny, Pa. (36). 1889. **C**
Phillips, Henry, jr., 1811 Walnut St., Philadelphia, Pa. (32). 1887. **H I**
Phippen, Geo. D., Salem, Mass. (18). 1874. **F**
Pickering, Prof. E. C., Director of Observatory, Cambridge, Mass. (18) 1875. **A B**
Pilling, James C., Box 591, Washington, D. C. (28). 1882. **F H I**
Pillsbury, Prof. John H., Smith College, Northampton, Mass. (23). 1885. **F H**
Platt, Franklin, Ass't Geologist, 2nd Geol. Survey of Pa., 1319 Walnut St., Philadelphia, Pa. (27). 1882. **E**
Plumb, Charles S., Purdue Univ., La Fayette, Ind. (36). 1890.
Pohlman, Dr. Julius, Buffalo, N. Y. (32). 1884. **E F**
Porter, Thos. C., LL.D., Lafayette College, Easton, Pa. (33). 1887. **F**
Potter, William B., Washington Univ., St. Louis, Mo. (25). 1879.
Powell, Major J. W., U. S. Geologist, 910 M St., N. W., Washington, D. C. (23). 1875. **E H**
Power, Prof. Frederick B., 225 Gregory Ave., Passaic, N. J. (31). 1887. **C**
Prentiss, Prof. A. N., Cornell Univ., Ithaca, N. Y. (35). 1887. **F**
Prentiss, D. Webster, M.D., 1101 14th St. N. W., Washington, D. C. (29). 1882. **F**
Prentiss, Robert W., Prof. of Mathematics and Astronomy, Rutgers College, New Brunswick, N. J. (40). 1891. **A**
Prescott, Prof. Albert B., Ann Arbor, Mich. (23). 1875. **C**
Preston, E. D., Ass't U. S. Coast and Geodetic Survey, Washington, D. C. (37). 1889. **A E**
Pritchett, Henry S., Director Observatory Washington University, St. Louis, Mo. (29). 1881. **A**
Prosser, Charles S., U. S. Geol. Survey, Washington, D. C. (33). 1891. **E F**
Pulsifer, Wm. H., Newton Centre, Mass. (26). 1879. **A H**
Pumpelly, Prof. Raphael, U. S. Geological Survey, Newport, R. I. (17). 1875. **E I**
Putnam, Prof. F. W., Curator Peabody Museum American Archæology and Ethnology, Cambridge, Mass. (Address as Permanent Secretary A. A. A. S., Salem, Mass.) (10). 1874. **H**
Pynchon, Rev. T. R., Trinity Coll., Hartford, Conn. (23). 1875.

Quincy, Edmund, 88 Clinton St., Boston, Mass. (11). 1874.

Rau, Eugene A., Bethlehem, Pa. (33). 1890. **F**
Rauch, Dr. John H., Springfield, Ill. (11). 1875.

Raymond, Rossiter W., 17 Burling Slip, New York, N. Y. (15). 1875. **E I**
Redfield, J. H., 216 W. Logan Square, Philadelphia, Pa. (1). 1874. **F**
Reed, E. Baynes, London, Ontario, Can. (27). 1882.
Rees, Prof. John K., Columbia College, New York, N. Y. (26). 1878. **A E B**
Reese, Jacob, 400 Chestnut St., Philadelphia, Pa. (33). 1891. **D B**
Remsen, Prof. Ira, Johns Hopkins Univ., Baltimore, Md. (22). 1875. **C**
Rice, John M., Northborough, Mass. (25). 1881. **A D**
Rice, Prof. Wm. North, Wesleyan University, Middletown, Conn. (18). 1874. **E F**
Richards, Prof. Charles B., 313 York St., New Haven, Conn. (33). 1885. **D**
Richards, Edgar, 113 E. 30 St., New York, N. Y. (31). 1886. **C**
Richards, Prof. Robert H., Mass. Inst. Tech., Back Bay, Boston, Mass. (22). 1875. **D**
Richards, Mrs. Robert H., Prof. Mass. Inst. of Tech., Back Bay, Boston, Mass. (23). 1878. **C**
Richardson, Clifford, Office of the Engineer Commissioner, Washington, D. C. (30). 1884. **C**
Ricketts, Prof. Palmer C., 17 1st St., Troy, N. Y. (33). 1887. **D A**
Ricketts, Prof. Pierre de Peyster, 104 John St., New York, N. Y. (26). 1880. **C D E**
Riley, Prof. C. V., U. S. Entomologist, 1700 13th St. N. W., Washington, D. C. (17). 1874. **F H I**
Risteen, Allen D., Hartford, Conn. (38). 1890. **A B D**
Ritchie, E. S., Newton Highlands, Mass. (10). 1877. **B**
Roberts, Prof. Isaac P., Ithaca, N. Y. (33). 1886. **I**
Robinson, Prof. Franklin C., Brunswick, Me. (29). 1889. **C D**
Robinson, Prof. S. W., Univ. of Ohio, Columbus, Ohio (30). 1883. **D B A**
Rockwell, Gen. Alfred P., Manchester, Mass. (10). 1882. **E**
Rockwell, Chas. H., Box 293, Tarrytown, N. Y. (28). 1883. **A D**
Rockwood, Prof. Charles G., jr., College of New Jersey, Princeton, N. J. (20). 1874. **A E B D**
Rogers, Fairman, 134 S. Fourth St., Philadelphia, Pa. (11). 1874.
Rogers, Prof. W. A., Colby Univ., Waterville, Me. (15). 1875. **A B D**
Rominger, Dr. Carl, Ann Arbor, Mich. (21). 1879. **E**
Rood, Prof. O. N., Columbia College, New York, N. Y. (14). 1875. **B**
Ross, Waldo O., 1 Chestnut St., Boston, Mass. (29). 1882.
Rowland, Prof. Henry A., Baltimore, Md. (29). 1880. **B**
Runkle, Prof. J. D., Mass. Institute of Technology, Boston, Mass. (2). 1875. **A D**
Rusby, Henry H., M.D., 169 Mt. Prospect Ave., Newark, N. J. (36). 1890. **F**
Russell, I. C., U. S. Geological Survey, Washington, D. C. (25). 1882. **E**
Rutherford, Lewis M., 175 Second Ave., New York, N. Y. (13). 1875.
Ryan, Harris J., Cornell Univ., Ithaca, N. Y. (38). 1890. **B**

Sadtler, Saml P., Ph.D., 1042 Drexel Building, Philadelphia, Pa. (22). 1875. **C**

Saegmuller, G. N., 132 Maryland Ave., S. W., Washington, D. C. (38). 1891. **A B**

Safford, Dr. James M., Nashville, Tenn. (6). 1875. **E C F**

Salisbury, Prof. R. D., Beloit College, Beloit, Wis. (37). 1890. **B E**

Salmon, Daniel E., Dep't of Agric., Washington, D. C. (31). 1885. **F**

Saunders, William, Director Agricultural Experiment Station, Ottawa, Ontario, Can. (17). 1874. **F**

SCHAEBERLE, J. M., Astronomer in the Lick Observatory, San José, Cal. (34). 1886. **A**

Schauck, Prof. J. Stillwell, Princeton, New Jersey (4). 1882. **C B H**

Schott, Charles A., U. S. Coast and Geodetic Survey Office, Washington, D. C. (8). 1874. **A**

Schweinitz, Dr. E. A. v., Dep't of Agriculture, Washington, D. C. (36). 1889. **C**

Schweitzer, Prof. Paul, State University of Missouri, Columbia, Mo. (24). 1877. **C B**

Scovell, M. A., Director Kentucky Agricultural Experiment Station, Lexington, Ky. (35). 1887.

Scribner, F. Lamson, Dep't of Agric., Washington, D. C. (34). 1887. **F**

SCUDDER, SAMUEL H., Cambridge, Mass. (13). 1874. **F**

Seaman, W. H., Chemist, 1424 11th St. N. W., Washington, D. C. (23). 1874. **C F**

Searle, Prof. Geo. M., Catholic Univ., Washington, D. C. (39). 1891. **A**

See, Horace, 1 Broadway, New York, N. Y. (34). 1886. **D**

Seiler, Carl, M.D., 1346 Spruce St., Philadelphia, Pa. (29). 1882. **F B**

Seymour, Arthur Bliss, Cambridge, Mass. (36). 1890. **F**

Seymour, William P., M.D., 105 Third St., Troy, N. Y. (19). 1888. **H**

Sharples, Stephen P., 13 Broad St., Boston, Mass. (29). 1884. **C**

Shimer, Porter W., E.M., Easton, Pa. (38). 1889. **C**

Shutt, Frank T., M.A., F.E.C., F.C.S., Chemist to the Dominion Experimental Farms, Ottawa, Ontario, Can. (38). 1889. **C**

Sias, Solomon, M.D., Schoharie, Schoharie Co., N. Y. (10). 1874.

Sigsbee, Chas. D., Comd'r U. S. N., U. S. Naval Acad., Annapolis, Md. (28). 1882. **D E**

Silliman, Prof. Justus M., Lafayette Coll., Easton, Pa. (19). 1874. **D E**

Simonds, Prof. Frederic W., Univ. of Texas, Austin, Texas (25). 1888 **E F**

Skinner, Joseph J., Massachusetts Inst. Technology, Boston, Mass. (23). 1880. **B**

Smiley, Charles W., U. S. Fish Commission, Washington, D. C. (28). 1883. **I**

Smith, Prof. Chas. J., 35 Adelbert St., Cleveland, Ohio (32). 1885. **A B**

Smith, Prof. Edgar F., Univ. of Penn., Philadelphia, Pa. (33). 1891. **C**

Smith, Edwin, Ass't U. S. Coast and Geodetic Survey, Washington, D. C. (30). 1882. **A B**

Smith, Prof. Erastus G., Beloit College, Beloit, Wis. (34). 1887. **C**
Smith, Erwin F., Dep't of Agric., Washington, D. C. (34). 1890. **F**
Smith, Prof. Eugene A., University, Ala. (20). 1877. **E C**
Smith, John B., Professor of Entomology, Rutgers College, New Brunswick, N. J. (32). 1884. **F**
Smith, Quintius C., M.D., No. 617 Colo. St., Austin, Texas (26). 1881. **F**
Smith, Prof. S. I., Yale College, New Haven, Conn. (18). 1875. **F**
Smith, Dr. Theobald, Bureau of Animal Industry, U. S. Dep't of Agric., Washington, D. C. (35). 1887. **F**
Smock, Prof. John Conover, Trenton, N. J. (23). 1879. **E**
Snow, Prof. F. H., Lawrence, Kan. (29). 1881. **F E**
Snow, Benj. W., Cornell Univ., Ithaca, N. Y. (35). 1889. **B**
Snyder, Henry, B.Sc., Miami Univ., Oxford, Ohio (30). 1888. **B C**
Snyder, Prof. Monroe B., High School Observatory, Philadelphia, Pa. (24). 1882. **A B**
Soule, R. H., Roanoke, Va. (33). 1886. **D**
Spalding, Volney M., Ann Arbor, Mich. (34). 1886. **F**
Spencer, Guilford L., Department Agriculture, Washington, D. C. (36). 1889. **C D**
Spencer, Prof. J. William, 7 Church St., Atlanta, Ga. (28). 1882. **E**
Spencer, John W., Paxton, Sullivan Co., Ind. (20). 1874.
Springer, Dr. Alfred, Box 621, Cincinnati, Ohio (24). 1880. **C**
Staley, Cady, LL.D., Pres. Case School of Applied Sciences, Cleveland, Ohio (37). 1888. **D**
Stearns, R. E. C., care Smithsonian Institution, Washington, D. C. (18). 1874. **F**
Steere, Prof. Jos. B., Ann Arbor, Mich. (34). 1890. **F H**
Stephens, W. Hudson, Lowville, N. Y. (18). 1874. **E H**
Sternberg, Col. George M., Surgeon U. S. A., Army Building, 39 Whitehall St., New York, N. Y. (24). 1880. **F**
Stevens, W. LeConte, 170 Joralemon St., Brooklyn, N. Y. (29). 1882. **B A C**
Stevenson, Prof. John J., Univ. of New York, New York, N. Y. (36). 1888.
Stockwell, John N., 1008 Case Avenue, Cleveland, Ohio (18). 1875. **A**
Stoddard, Prof. John T., Smith College, Northampton, Mass. (35). 1889. **B C**
Stokes, Henry Newlin, Ph.D., U. S. Geol. Survey, Washington, D. C. (38). 1891. **C E**
Stone, George H., Colorado Springs, Col. (29). 1882. **E F**
Stone, Mrs. Leander, Pres. Y. W. C. A., 3352 Indiana Avenue, Chicago, Ill. (22). 1874. **F E**
Stone, Ormond, Director Leander McCormick Observatory, University of Virginia, Va. (24). 1876. **A**
Stone, Prof. Winthrop E., Purdue Univ., La Fayette, Ind. (39). 1891. **C**
Story, Prof. Wm. E., Clark Univ., Worcester, Mass. (29). 1881. **A**
Stowell, Prof. T. B., Potsdam, N. Y. (28). 1885. **F**
Stringham, Prof. Irving, Univ. of Cal., Berkeley, Cal. (33). 1885. **A**

Stuart, Prof. A. P. S., Lincoln, Nebraska (21). 1874. **C**
Sturtevant, E. Lewis, M.D., So. Framingham, Mass. (29). 1882. **F**
Swallow, Prof. C. G., 19½ Main St., Helena, Montana (10). 1875.
Swift, Lewis, Ph.D., Rochester, N. Y. (29). 1882. **A**

Tainter, Charles Sumner, 1843 S, cor. 19 St., Washington, D. C. (29). 1881. **B D A**
Taylor, H. C., Commander U. S. N. (30). 1889.
Taylor, Thos., M.D., Department of Agriculture, Washington, D. C. (29). 1885. **F C**
Taylor, William B., Smithsonian Institution, Washington, D. C. (29). 1881. **B A**
Terry, Prof. N. M., U. S. Naval Academy, Annapolis, Md. (23). 1874. **B**
Thomas, Benj. F., Ph.D., State Univ., Columbus, Ohio (29). 1882. **B A**
Thomson, Elihu, Thomson-Houston Electric Co., Lynn, Mass. (37). 1888. **B**
Thomson, Wm., M.D., 1426 Walnut St., Philadelphia, Pa. (33). 1885. **B**
Thruston, Gates Phillips, Nashville, Tenn. (38). 1890. **H**
Thurston, Prof. R. H., Sibley College, Cornell University, Ithaca, N. Y. (23). 1875. **D**
Tittmann, Otto H., U. S. Coast and Geodetic Survey Office, Washington, D. C. (24). 1888. **A**
Todd, Prof. David P., Director Lawrence Observatory, Amherst College, Amherst, Mass. (27). 1881. **A B D**
Todd, Prof. James E., Tabor, Fremont Co., Iowa (22). 1886. **E F**
Towne, Henry R., Pres. Yale and Towne Manufacturing Co., Stamford, Conn. (33). 1888. **D B**
Townshend, Prof. N. S., Ohio State Univ., Columbus, Ohio (17). 1881. **F H**
Tracy, Sam'l M., Agricultural College, Miss. (27). 1881. **F**
Traphagen, Frank W., Ph.D., Prof. of Chem., The College of Montana, Deer Lodge City, Montana (35). 1889. **C F E**
Trelease, Dr. Wm., Director Missouri Botanical Gardens, St. Louis, Mo. (39). 1891 **F**
Trimble, Prof. Henry, 145 No. 10 St., Philadelphia, Pa. (34). 1889. **C**
True, Fred W., U. S. National Museum, Washington, D. C. (28). 1882. **F**
Trumbull, Dr. J. Hammond, Hartford, Conn. (29). 1882. **H**
Tucker, Willis G., M.D., Albany Med. Coll., Albany, N. Y. (29). 1888. **C**
Tuckerman, Alfred, Ph.D., 61 Kay St., Newport, R. I. (39). 1891. **C**
Tuttle, Prof. Albert H., Univ. of Virginia, Va. (17). 1874. **F**
Twitchell, E., 559 W. Seventh St., Cincinnati, Ohio (39). 1891. **C**

Uhler, Philip R., 254 W. Hoffman St., Baltimore, Md. (19). 1874. **F E**
Underwood, Prof. Lucien M., 411 Comstock Ave., Syracuse, N. Y. (33). 1885. **F**
Upham, Warren, 36 Newbury St., Somerville, Mass. (25). 1880. **E**
Upton, Winslow, Brown Univ., Providence, R. I. (29). 1883. **A**

Van der Weyde, P. H., M.D., 236 Duffield St., Brooklyn, N. Y. (17). 1874. **B**

Van Dyck, Prof. Francis Cuyler, New Brunswick, N. J. (28). 1882. **B C F**
Van Hise, Charles R., Univ. of Wisconsin, Madison, Wis. (37). 1890.
Van Vleck, Prof. John M., Middletown, Conn. (23). 1875. **A**
Vasey, George, M.D., Dep't of Agric., Washington, D. C. (32). 1889. **F**
Venable, Prof. F. P., Chapel Hill, N. C. (39). 1891. **C**
Very, Samuel W., Lieut. Comdr. U. S. N., Robeson St., Jamaica Plain, Mass. (28). 1886. **A B**
Vining, Edward P., 816 Olive St., St. Louis, Mo. (32). 1887. **H**
Vogdes, A. W., Fort Canby, Pacific Co., Washington (32). 1885. **E F**

Wachsmuth, Charles, 111 Marietta St., Burlington, Iowa (30). 1884. **E F**
Wadsworth, Prof. M. Edward, Ph.D., Director of the Michigan Mining School, State Geologist of Michigan, Houghton, Mich. (23). 1874. **E**
Walcott, Charles D., U. S. Geological Survey, Washington, D. C. (25). 1882. **E F**
Waldo, Prof. Clarence A., Greencastle, Ind. (37). 1889. **A**
Wallace, Wm., Ansonia, Conn. (28). 1882.
Waller, E., School of Mines, Columbia College, New York, N. Y. (23). 1874.
Walmsley, W. H., 1016 Chestnut St., Philadelphia, Pa. (28). 1883. **F**
Wanner, Atreus, York, York Co., Pa. (36). 1890. **H**
Ward, Prof. Henry A., Rochester, N. Y. (13). 1875. **F E H**
Ward, Lester F., U. S. Geological Survey, Washington, D. C. (26). 1879. **E F**
Ward, Dr. R. H., 53 Fourth St., Troy, N. Y. (17). 1874. **F B**
Ward, Wm. E., Port Chester, N. Y. (36). 1889. **D**
Warder, Prof. Robert B., Howard Univ., Washington, D. C. (19). 1881. **C B**
Warner, James D., 199 Baltic St., Brooklyn, N. Y. (18). 1874. **A B**
Warner, Worcester R., 887 Case Ave., Cleveland, Ohio (33). 1888. **A B D**
Warren, Cyrus M., Brookline, Mass. (29). 1882. **C**
Warren, Dr. Joseph W., Bryn Mawr College, Bryn Mawr, Pa. (31). 1886. **F**
Warren, Prof. S. Edward, Newton, Mass. (17). 1875. **A–I**
Watson, Prof Wm., 107 Marlborough St., Boston, Mass. (12). 1884. **A**
Webb, Prof. J. Burkitt, Stevens Inst., Hoboken, N. J. (31). 1883. **D B A**
Weber, Prof. Henry A., Ohio State Univ., Columbus, Ohio (35). 1888. **F**
Webster, F. M., La Fayette, Ind. (35). 1890.
Webster, Prof. N. B., Grove House, Vineland, N. J. (7). 1874. **B C E**
Weed, Clarence M., Hanover, N. H. (38). 1890.
Weston, Edward, 645 High St., Newark, N. J. (33). 1887. **B C D**
Wheatland, Dr. Henry, President Essex Inst., Salem, Mass. (1). 1874.
Wheeler, Prof. C. Gilbert, 81 Clark St., Chicago, Ill. (18). 1883. **C E**
Wheeler, Orlando B., Office Mo. River Com., 1515 Lucas Place, St. Louis, Mo. (24). 1882. **A D**
White, Prof. C. A., Le Droit Park, Washington, D. C. (17). 1875. **E F**
White, Prof. H. C., Univ. of Georgia, Athens, Ga. (29). 1885. **C**
White, Prof. I. C., Univ. of W. Va., Morgantown, W. Va. (25). 1882. **E**

Whiteaves, J. F., Geol. Survey, Ottawa, Ontario, Can. (31). 1887. **E F**

Whitfield, R. P., American Museum Natural History, 77th St. & 8th Avenue, New York, N. Y. (18). 1874. **E F H**

Whiting, Miss Sarah F., Wellesley College, Wellesley, Mass. (31). 1883. **B A**

Whitman, Prof. Frank P., Adelbert College, Cleveland, Ohio (33). 1885. **A B**

Wilbur, A. B., Middletown, N. Y. (23). 1874.

Wiley, Prof. Harvey W., Dep't of Agric., Washington, D.C. (21). 1874. **C**

Williams, Benezette, 171 La Salle St., Chicago, Ill. (33). 1887. **D**

Williams, Charles H., M.D., C. B. and Q. Gen. Office, Adams St., Chicago, Ill. (22). 1874.

Williams, Geo. Huntington, Johns Hopkins Univ., Baltimore, Md. (33). 1886. **E**

Williams, Henry Shaler, Cornell Univ., Ithaca, N. Y. (18). 1882. **E F**

Williams, Prof. Henry W., 15 Arlington St., Boston, Mass. (11). 1874. **H F**

Williams, J. Francis, Salem, N. Y. (31). 1890. **C E**

Williams, Prof. S. G., Cornell Univ., Ithaca, N. Y. (33). 1885. **E**

Willis, Bailey, U. S. Geol. Survey, Washington, D. C. (36). 1890.

Willmott, Arthur B., 6 Little's Block, Cambridge, Mass. (38). 1890.

Willson, Prof. Frederick N., Princeton, N. J. (33). 1887. **A D**

Willson, Robert W., Cambridge, Mass. (30). 1890. **B A**

Wilson, Sir Daniel, President University College, 117 Bloor St., Toronto, Ontario, Canada (25). 1876. **H E**

Wilson, Joseph M., Room 1036, Drexel Building, Philadelphia, Pa. (33). 1886. **D**

Wilson, Thomas, U. S. Nat'l Museum, Washington, D. C. (36). 1888. **H**

Wilson, William Powell, 640 No. 32nd St., Philadelphia, Pa. (38). 1889. **F**

Winchell, Horace V., 10 State St., Minneapolis, Minn. (34). 1890. **E C**

Winchell, Prof. N. H., Univ. of Minnesota, Minneapolis, Minn. (19). 1874. **E H**

Wing, Henry H., Cornell Univ., Experimental Station, Ithaca, N. Y. (38). 1890.

Winlock, Wm. C., Smithsonian Institution, Washington, D. C. (33). 1885. **A B**

Winslow, Arthur, State Geologist, Jefferson City, Mo. (37). 1889. **E**

Withers, Prof. W. A., Agric. and Mechanical College, Raleigh, N. C. (33). 1891. **C**

Witthaus, Dr. R. A., 410 E. 26th St., New York, N. Y. (35). 1890.

Wood, Prof. De Volson, Hoboken, N. J. (29). 1881.

Woodbury, C. J. H., 31 Milk St., Boston, Mass. (29). 1884. **D**

Woodward. Prof. Calvin M., 1761 Missouri Ave., St. Louis, Mo. (32). 1884. **D A I**

Woodward, R. S., U. S. Geol. Survey, Washington, D. C. (33). 1885. **A B D**

Wormley, T. G., Univ. of Pennsylvania, Philadelphia, Pa. (20). 1878.
Worthen, W. E., 63 Bleeker St., New York, N. Y. (36). 1888. **D**
Wrampelmeier, Theo. J., Berkeley, Cal. (34). 1887. **C**
Wright, Prof. Albert A., Oberlin College, Oberlin, Ohio (24). 1880. **E F**
Wright, Prof. Arthur W., Yale Coll., New Haven, Conn. (14). 1874. **A B**
Wright, Rev. Geo. F., Oberlin College, Oberlin, Ohio (29). 1882. **E**
Wright, Prof. R. Ramsay, Toronto, Ontario, Can. (38). 1890. **F**
Wright, Prof. Thos. W., Union College, Schenectady, N. Y. (36). 1889.
Würtele, Rev. Louis C., Acton Vale, P. Q., Can. (11). 1875. **E**

Youmans, Wm. Jay, M.D., Popular Science Monthly, 1–5 Bond St., New York, N. Y. (28). 1889. **F C**
Young, A. V. E., Northwestern Univ., Evanston, Ill. (33). 1886. **C B**
Young, C. A., Prof. of Astronomy, College of New Jersey, Princeton, N. J. (18). 1874. **A B D**

Zalinski, E. L., Capt. 5th Artillery, U. S. A., Fort Hamilton, New York Harbor, N. Y. (36). 1891. **D**
Ziwet, Alexander, 6 N. Division St., Ann Arbor, Mich. (38). 1890. **A**

[779 FELLOWS.]

SUMMARY.—PATRONS, 3; CORRESPONDING MEMBERS, 3; MEMBERS, 1269; HONORARY FELLOWS, 2; FELLOWS, 777.
JULY 8, 1892, TOTAL NUMBER OF MEMBERS OF THE ASSOCIATION, 2054.

DECEASED MEMBERS.

[Unless by special vote of the Council, the names of those only who are members of the Association at the *time of their decease* will be included in this list. Information of the date and place of birth and death, to fill blanks in this list, is requested by the Permanent Secretary.]

Abbe, George W., New York, N. Y. (23). Died Sept. 25, 1879.

Abert, John James, Washington, D. C. (1). Born in Shepherdstown, Va., Sept. 17, 1788. Died in Washington, D. C., Sept. 27, 1863.

Adams, Charles Baker, Amherst, Mass. (1). Born in Dorchester, Mass., Jan. 11, 1814. Died in St. Thomas, W. I., Jan. 19, 1853.

Adams, Edwin F., Charlestown, Mass. (18).

Adams, Samuel, Jacksonville, Ill. (18). Born Dec. 19, 1806. Died April 29, 1877.

Agassiz, Louis, Cambridge, Mass. (1). Born in Parish of Motier, Switzerland, May 28, 1807. Died in Cambridge, Mass., Dec. 14, 1873.

Ainsworth, J. G., Barry, Mass. (14).

Alexander, Stephen, Princeton, N. J. (1). Born Sept. 1, 1806. Died June 25, 1883.

Allen, Thomas, St. Louis, Mo. (27). Died April 8, 1882.

Allen, Zachariah, Providence, R. I. (1). Born in Providence, R. I., Sept. 15, 1795. Died March 17, 1882.

Allston, Robert Francis Withers, Georgetown, S. C. (3). Born in All Saints Parish, S. C., April 21, 1801. Died near Georgetown, S. C., April 7, 1864.

Alvord, Benjamin, Washington, D. C. (17). Born in Rutland, Vt., Aug. 18, 1813. Died Oct. 16, 1884.

Ames, M. P., Springfield, Mass. (1). Born in 1803. Died April 23, 1847.

Andrews, Ebenezer Baldwin, Lancaster, Ohio (7). Born in Danbury, Conn., April 29, 1821. Died in Lancaster, Ohio, Aug. 14, 1880.

Anthony, Charles H., Albany, N. Y. (6). Died in 1874.

Appleton, Nathan, Boston, Mass. (1). Born in New Ipswich, N. H., Oct. 6, 1779. Died July 14, 1861.

Armstrong, John W., Fredonia, N. Y. (24).

Ashburner, Charles A., Pittsburgh, Pa. (31). Died Dec. 24, 1889.

Ashburner, Wm., San Francisco, Cal. (29). Born in Stockbridge, Mass., March, 1831. Died in San Francisco, Cal., April 20, 1887.

Atwater, Mrs. S. T., Chicago, Ill. (17). Born Aug. 8, 1812. Died April 11, 1878.

Aufrecht, Louis, Cincinnati, Ohio (30).

Baba, Tatui, New York, N. Y. (36).

Babbitt, Miss Franc E., Coldwater, Mich. (32). Died near Coldwater, Mich., July 6, 1891, aged 67.

Bache, Alexander Dallas, Washington, D. C. (1). Born in Philadelphia, Pa., July 19, 1806. Died at Newport, R. I., Feb. 17, 1867.

Bache, Franklin, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Oct. 25, 1792. Died March 19, 1864.

Bailey, Jacob Whitman, West Point, N. Y. (1). Born in Auburn, Mass., April 29, 1811. Died in West Point, N. Y., Feb. 26, 1857.

Baird, Spencer Fullerton, Washington, D. C. (1). Born in Reading, Pa., Feb. 3, 1823. Died in Wood's Holl, Mass., Aug. 19, 1887.

Bardwell, F. W., Lawrence, Kan. (13). Died in 1878.

Barnard, F. A. P., New York, N. Y. (7). Born in Sheffield, Mass., May 5, 1809. Died in New York, April 27, 1889.

Barnard, John Gross, New York, N. Y. (14). Born in Sheffield, Mass., May 19, 1815. Died in Detroit, Mich., May 14, 1882.

Barrett, Dwight H., Baltimore, Md. (36). Died in March, 1889.

Barrett, Moses, Milwaukee, Wis. (21). Died in 1873.

Barry, Redmond, Melbourne, Australia (25).

Bassett, Daniel A., Los Angeles, Cal. (29). Born Dec. 8, 1819. Died May 26, 1887.

Bassnett, Thomas, Jacksonville, Fla. (8). Born 1807. Died in Jacksonville, Fla., Feb. 16, 1886.

Batchelder, John M., Cambridge, Mass. (8).

Bayne, Herbert Andrew, Kingston, Ont., Can. (29). Born in Londonderry, Nova Scotia, Aug. 16, 1846. Died in Pictou, Can., Sept. 16, 1886.

Beach, J. Watson, Hartford, Conn. (23). Born Dec. 28, 1823. Died Mar. 16, 1887.

Beck, C. F., Philadelphia, Pa. (1).

Beck, Lewis Caleb, New Brunswick, N. J. (1). Born in Schenectady, N. Y., Oct. 4, 1798. Died April 20, 1853.

Beck, Theodoric Romeyn, Albany, N. Y. (1). Born in Schenectady, N. Y., Aug. 11, 1791. Died in Utica, N. Y., Nov. 19, 1855.

Beckwith, Henry C., Coleman's Station, N. Y. (29). Died July 12, 1885.

Belfrage, G. W., Clifton, Texas (29). Died Dec. 7, 1882.

Belknap, William B., Louisville, Ky. (29).

Bell, Samuel N., Manchester, N. H. (7). Born in Chester, N. H., March 25, 1829. Died in Manchester, N. H., Feb. 8, 1889.

Belt, Thomas, London, Eng. (27). Died Sept. 8, 1878.

Benedict, George Wyllys, Burlington, Vt. (16). Born Jan. 11, 1796. Died Sept. 23, 1871.

Bicknell, Edwin, Boston, Mass. (18). Born in 1830. Died March 19, 1877.

Binney, Amos, Boston, Mass. (1). Born in Boston, Mass., Oct. 18, 1803. Died in Rome, Feb. 18, 1847.

Binney, John, Boston, Mass. (3).

Blackie, Geo. S., Nashville, Tenn. (26).

Blair, Henry W., Washington, D. C. (26). Died Dec. 15, 1884.

Blake, Eli Whitney, New Haven, Conn. (1). Born Jan. 27, 1795. Died Aug. 18, 1886.

Blake, Francis C., Mansfield Valley, Pa. (29). Died Feb. 21, 1891.

Blake, Homer Crane, New York, N. Y. (28). Born in Cleveland, Ohio, Feb. 1, 1822. Died in New York, N. Y., Jan. 20, 1880.
Blanding, William, ——, R. I. (1).
Blatchford, Thomas W., Troy, N. Y. (6).
Blatchley, Miss S. L., New Haven, Conn. (19). Died March 13, 1873.
Boadle, John, Haddonfield, N. J. (20). Born in 1805. Died in July, 1878.
Bomford, George, Washington, D. C. (1). Born in New York, N. Y., 1780. Died in Boston, Mass., March 25, 1848.
Bowditch, Henry Ingersoll, Boston, Mass. (2). Born in Salem, Mass., Aug. 9, 1808. Died in Boston, Mass., Jan. 14, 1892.
Bowles, Miss Margaretta, Columbia, Tenn. (26). Died July, 1887.
Bowron, James, South Pittsburg, Tenn. (26). Died in Dec., 1877.
Bradley, Leverette, Jersey City, N. J. (15). Died in 1875.
Braithwaite, Jos., Chambly, C. W. (11).
Breckinridge, S. M., St. Louis, Mo. (27). Died May 28, 1891.
Briggs, Albert D., Springfield, Mass. (13). Died Feb. 20, 1881.
Briggs, Robert, Philadelphia, Pa. (29). Born May 18, 1822. Died July 24, 1882.
Brigham, Charles Henry, Ann Arbor, Mich. (17). Born in Boston, Mass., July 27, 1820. Died Feb. 19, 1879.
Bross, William, Chicago, Ill. (7). Died in 1890.
Brown, Andrew, Natchez, Miss. (1).
Brown, Horace, Salem, Mass. (27). Died in July, 1883.
Bull, John, Washington, D. C. (31). Born Aug. 1, 1819. Died June 9, 1884.
Bulloch, Walter H., Chicago, Ill. (30).
Burbank, L. S., Woburn, Mass. (18).
Burgess, Edward, Boston, Mass. (22). Born in Barnstable, Mass., June 30, 1848. Died in Boston, July 12, 1891.
Burke, Joseph Chester, Middletown, Conn. (29). Died in 1885.
Burnap, George Washington, Baltimore, Md. (12). Born in Merrimack, N. H., Nov. 30, 1802. Died in Philadelphia, Pa., Sept. 8, 1859.
Burnett, Waldo Irving, Boston, Mass. (1). Born in Southborough, Mass., July 12, 1828. Died in Boston, Mass., July 1, 1854.
Butler, Thomas Belden, Norwalk, Conn. (10). Born Aug. 22, 1806. Died June 8, 1873.

Cairns, Frederick A., New York, N. Y. (27). Died in 1879.
Campbell, Mrs. Mary H., Crawfordsville, Ind. (22). Died Feb. 27, 1882.
Carpenter, Thornton, Camden, S. C. (7).
Carpenter, William M., New Orleans, La. (1).
Case, Leonard, Cleveland, Ohio (15). Born June 27, 1820. Died Jan. 5, 1880.
Case, William, Cleveland, Ohio (6).
Caswell, Alexis, Providence, R. I. (2). Born Jan. 29, 1799. Died in Providence, R. I., Jan. 8, 1877.
Chadbourne, Paul Ansel, Amherst, Mass. (10). Born in North Berwick, Me., Oct. 21, 1823. Died Feb. 23, 1883.
Chapman, Nathaniel, Philadelphia, Pa. (1). Born in Alexandria Co., Va., May 28, 1780. Died July 1, 1853.

Chase, Pliny Earle, Haverford College, Pa. (18). Born in Worcester, Mass., Aug. 18, 1820.

Chase, Stephen, Hanover, N. H. (2). Born in 1813. Died Aug. 5, 1851.

Chauvenet, William, St. Louis, Mo. (1). Born May 24, 1819. Died Dec. 13, 1870.

Cheesman, Louis Montgomery, Hartford, Conn. (32). Born in 1858. Died in Jan., 1885.

Cheney, Miss Margaret S., Jamaica Plain, Mass. (29). Died in 1882.

Chevreul, Michel Eugène, Paris, France (35). Born in Angiers, France, Aug. 31, 1786. Died April 9, 1889.

Clapp, Asahel, New Albany, Ind. (1). Born Oct. 5, 1792. Died Dec. 15, 1862.

Clark, Henry James, Cambridge, Mass. (13). Born in Easton, Mass., June 22, 1826. Died in Amherst, Mass., July 1, 1873.

Clark, Joseph, Cincinnati, Ohio (5).

Clark, Patrick, Rahway, N. J. (33). Died March 5, 1887.

Clarke, A. B., Holyoke, Mass. (13).

Cleaveland, C. H., Cincinnati, Ohio (9).

Cleveland, A. B., Cambridge, Mass. (2).

Coffin, James Henry, Easton, Pa. (1). Born in Northampton, Mass., Sept. 6, 1806. Died Feb. 6, 1873.

Coffin, John H. C., Washington, D. C. (1). Born in Wiscasset, Maine, Sept. 14, 1815. Died in Washington, D. C., Jan. 8, 1890.

Coffinberry, Wright Lewis, Grand Rapids, Mich. (20). Born in Lancaster, Ohio, April 5, 1807. Died in Grand Rapids, Mich., March 26, 1889.

Colburn, E. M., Peoria, Ill. (33). Born in Rome, N. Y., Sept. 13, 1813. Died in Peoria, Ill., May 29, 1890.

Cole, Frederick, Montreal, Can. (31). Died in 1887.

Cole, Thomas, Salem, Mass. (1). Born Dec. 24, 1779. Died June 24, 1852.

Coleman, Henry, Boston, Mass. (1).

Collins, Frederick, Washington, D. C. (28). Born Dec. 5, 1842. Died Oct. 27, 1881.

Conrad, Timothy Abbott, Philadelphia, Pa. (1). Born in New Jersey, June 21, 1803. Died Aug. 9, 1877.

Cook, George H., New Brunswick, N. J. (4). Born in Hanover, Morris County, in 1818. Died in New Brunswick, N. J., Sept. 22, 1889.

Cooke, Caleb, Salem, Mass. (18). Born Feb. 15, 1838. Died June 5, 1880.

Cooper, William, Hoboken, N. J. (9). Died in 1864.

Cope, Mary S., Germantown, Pa. (33). Born in Germantown, Pa., July 13, 1853. Died in Germantown, Jan. 4, 1888.

Copes, Joseph S., New Orleans, La. (11). Born Dec. 9, 1811. Died March 1, 1885.

Corning, Erastus, Albany, N. Y. (6). Born in Norwich, Conn., Dec. 14, 1794. Died April 9, 1872.

Costin, M. P., Fordham, N. Y. (30). Died June 8, 1884.

Couper, James Hamilton, Darien, Ga. (1). Born March 5, 1794. Died July 3, 1866.

Cramp, John Mockett, Wolfville, N. S. (11). Born in Kent, England, July 25, 1796. Died Dec. 6, 1881.

Crehore, John D., Cleveland, Ohio (24).

Crocker, Charles F., Lawrence, Mass. (22). Died in July, 1881.

Crocker, Miss Lucretia, Boston, Mass. (29). Died in 1886.

Crosby, Alpheus, Salem, Mass. (10). Born in Sandwich, N. H., Oct. 13, 1810. Died April 17, 1874.

Crosby, Thomas Russell, Hanover, N. H. (18). Born Oct. 22, 1816. Died March 1, 1872.

Crosier, Edward S., New Albany, Ind. (29). Died in June, 1891.

Croswell, Edwin, Albany, N. Y. (6). Born in Catskill, N. Y., May 29, 1797. Died June 13, 1871.

Crow, Wayman, St. Louis, Mo. (27). Born March 7, 1808. Died May 10, 1885.

Cummings, Joseph, Evanston, Ill. (13). Born in Falmouth, Me., March 3, 1817. Died in Evanston, Ill., May 7, 1890.

Curry, W. F., Geneva, N. Y. (11).

Curtis, Josiah, Washington, D. C. (18). Died Aug. 1, 1883.

Da Costa, Chas. M., New York, N. Y. (36). Died in 1890.

Dalrymple, Edwin Augustine, Baltimore, Md. (11). Born in Baltimore, Md., June 4, 1817. Died Oct. 30, 1881.

Danforth, Edward, Elmira, N. Y. (11). Died in Elmira, N. Y., June 13, 1888.

Davenport, H. W., Washington, D. C. (30).

Day, Austin G., New York, N. Y. (29). Died Dec. 28, 1889.

Dayton, Edwin A., Madrid, N. Y. (7). Born in 1827. Died June 24, 1873.

Dean, Amos, Albany, N. Y. (6). Born in Barnard, Vt., Jan. 16, 1803. Died Jan. 26, 1868.

Dearborn, George H. A. S., Roxbury, Mass. (1).

Dekay, James Ellsworth, New York, N. Y. (1). Born in New York, 1792. Died Nov. 21, 1851.

Delano, Joseph C., New Bedford, Mass. (5). Born Jan. 9, 1796. Died Oct. 16, 1886.

De Laski, John, Carver's Harbor, Me. (18).

Devereux, John Henry, Cleveland, Ohio (18). Born in Boston, Mass., April 5, 1832. Died in Cleveland, Ohio, March 17, 1886.

Dewey, Chester, Rochester, N. Y. (1). Born in Sheffield, Mass., Oct. 25, 1781. Died Dec. 15, 1867.

Dexter, G. M., Boston, Mass. (11).

Dillingham, W. A. P., Augusta, Me. (17).

Dimmick, L. N., Santa Barbara, Cal. (29). Died May 31, 1884.

Dinwiddie, Hardaway H., College Station, Texas (32). Died Dec. 11, 1887.

Dinwiddie, Robert, New York, N. Y. (1). Born in Dumfries, Scotland, July 23, 1811. Died in New York, N. Y., July 12, 1888.

Dixwell, Geo. B., Boston, Mass. (29). Died April, 1885.

Doggett, George Newell, Chicago, Ill. (33). Born in Chicago, Ill., Dec. 19, 1858. Died in Fredericksburg, Va., Jan. 15. 1887.

Doggett, Mrs. Kate Newell, Chicago, Ill. (17). Born in Castleton, Vt., Nov. 5, 1828. Died in Havana, Cuba, March 13, 1884.

Doggett, Wm. E., Chicago, Ill. (17). Born Nov. 20, 1820. Died in 1876.

Doolittle, L., Lenoxville, C. E. (11). Died in 1862.

Dorr, Ebenezer Pearson, Buffalo, N. Y. (25). Born in Hartford, Vt. Died in Buffalo, N. Y., April 29, 1882.

Draper, Henry, New York, N. Y. (28). Born in New York, N. Y., March 7, 1837. Died Nov. 20, 1882.

Ducatel, Julius Timoleon, Baltimore, Md. (1). Born in Baltimore, Md., June 6, 1798. Died April 25, 1849.

Duffield, George, Detroit, Mich. (10). Born in Strasburg, Pa., July 4, 1794. Died in Detroit, Mich., June 26, 1869.

Dumont, A. H., Newport, R. I. (14).

Dun, Walter Angus, Cincinnati, Ohio (31). Born March 1, 1857. Died Nov. 7, 1887.

Duncan, Lucius C., New Orleans, La. (10). Born in 1801. Died Aug. 9, 1855.

Dunn, R. P., Providence, R. I. (14).

Dury, Henry M., Nashville, Tenn. (33). Died April 15, 1891.

Eads, James Buchanan, New York, N. Y. (27). Born May 23, 1820. Died March 8, 1887.

Easton, Norman, Fall River, Mass. (14). Died Dec. 21, 1872.

Eaton, James H., Beloit, Wis. (17). Died Jan. 5, 1877.

Elliott, Ezekiel Brown, Washington, D. C. (10). Born July 16, 1823. Died May 24, 1888.

Elsberg, Louis, New York, N. Y. (23). Born in Iserlohn, Prussia, April 2, 1836. Died in New York, N. Y., Feb. 19, 1885.

Elwyn, Alfred Langdon, Philadelphia, Pa. (1). Born in Portsmouth, N. H., July 9, 1804. Died in Philadelphia, Pa., March 15, 1884.

Ely, Charles Arthur, Elyria, Ohio (4).

Emerson, Geo. Barrell, Boston, Mass. (1). Born in Kennebunk, Me., Sept. 12, 1797. Died March 14, 1881.

Emmons, Ebenezer, Williamstown, Mass. (1). Born in Middlefield, Mass., May 16, 1799. Died October 1, 1863.

Engelmann, George, St. Louis, Mo. (1). Born in Frankfort-on-the Main, Germany, Feb. 2, 1809. Died Feb. 4, 1884.

Engstrom, A. B., Burlington, N. J. (1).

Eustis, Henry Lawrence, Cambridge, Mass. (2). Born Feb. 1, 1819. Died Jan. 11, 1885.

Evans, Asher B., Lockport, N. Y. (19). Born in Hector, N. Y., Sept. 21, 1834. Died in Lockport, Sept. 24, 1891.

Evans, Edwin, Streator, Ill. (30). Died May 5, 1889.

Everett, Edward, Boston, Mass. (2). Born in Dorchester, Mass., April 11, 1794. Died in Boston, Mass., Jan. 15, 1865.

Ewing, Thomas, Lancaster, Ohio (5). Born in Ohio Co., Va., Dec. 28, 1789. Died Oct. 26, 1871.

Faries, R. J., Wauwatosa, Wis. (21). Died May 31, 1878.
Farnam, J. E., Georgetown, Ky. (26).
Farquharson, Robert James, Des Moines, Iowa (24). Born July 15, 1824. Died Sept. 6, 1884.
Felton, Samuel Morse, Philadelphia, Pa. (29). Born in Newbury, Mass., July 19, 1809. Died in Philadelphia, Pa., Jan. 24, 1889.
Ferrel, William, Kansas City, Mo. (11). Died Sept. 18, 1891.
Ferris, Isaac, New York, N. Y. (6). Born in New York, Oct. 9, 1798. Died in Roselle, N. J., June 16, 1873.
Feuchtwanger, Lewis, New York, N. Y. (11). Born in Fürth, Bavaria, Jan. 11, 1805. Died in New York, N. Y., June 25, 1876.
Ficklin, Joseph, Columbia, Mo. (20). Born in Winchester, Ky., Sept. 9, 1833. Died in Columbia, Mo., Sept. 6, 1887.
Fillmore, Millard, Buffalo, N. Y. (7). Born in New York, Jan. 7, 1800. Died March 8, 1874.
Fisher, Mark, Trenton, N. J. (10).
Fitch, Alexander, Hartford, Conn. (1). Born March 25, 1799. Died Jan. 20, 1859.
Fitch, O. H., Ashtabula, Ohio (7). Born in 1803. Died Sept. 17, 1882.
Floyd, Richard S., San Francisco, Cal. (34). Died Oct. 17, 1890.
Foote, Herbert Carrington, Cleveland, Ohio (35). Born in 1852. Died in Cleveland, Aug. 24, 1888.
Forbush, E. B., Buffalo, N. Y. (15).
Force, Peter, Washington, D. C. (4). Born in New Jersey, Nov. 26, 1790. Died in Washington, D. C., Jan. 23, 1868.
Ford, A. C., Nashville, Tenn. (26).
Forshey, Caleb Goldsmith, New Orleans, La. (21). Born in Somerset Co., Pa., July 18, 1812. Died in Carrollton, La., July 25, 1881.
Foster, John Wells, Chicago, Ill. (1). Born in Brimfield, Mass., March 4, 1815. Died in Chicago, Ill., June 29, 1873.
Foucon, Felix, Madison, Wis. (18).
Fowle, Wm. Bentley, Boston, Mass. (1). Born in Boston, Mass., Oct. 17, 1795. Died Feb. 6, 1865.
Fox, Charles, Grosse Ile, Mich. (7).
Fox, Joseph G., Easton, Pa. (31). Born in Adams, N. Y., Sept. 7, 1833. Died in Easton, Pa., Dec. 27, 1889.
Frazer, John Fries, Phila., Pa. (1). Born July 8, 1812. Died Oct. 12, 1872.
Freeman, Spencer Hedden, Cleveland, Ohio (29). Born Oct. 3, 1855. Died Feb. 2, 1886.
French, John William, West Point, N. Y. (11). Born in Connecticut, about 1810. Died in West Point, N. Y., July 8, 1871.
Frothingham, Frederick, Milton, Mass. (11).
Fuller, H. Weld, Boston, Mass. (29). Died Aug. 14, 1889.

Garber, A. P., Columbia, Pa. (29). Died Aug. 26, 1881.
Gardiner, Frederic, Middletown, Conn. (23). Born in Gardiner, Me., Oct. 22, 1822. Died in Middletown, Conn., July 17, 1889.
Garrison, H. D., Chicago, Ill. (31). Died in Feb., 1891.

Gavit, John E., New York, N. Y. (1). Born in New York, Oct. 29, 1819. Died in Stockbridge, Mass., Aug. 25, 1874.

Gay, Martin, Boston, Mass. (1). Born in 1804. Died Jan. 12, 1850.

Gibbon, J. H., Charlotte, N. C. (3).

Gillespie, William Mitchell, Schenectady, N. Y. (10). Born in New York, N. Y., 1816. Died in New York, Jan. 1, 1868.

Gilmor, Robert, Baltimore, Md. (1).

Glazier, W. W., Key West, Fla. (29). Died Dec. 11, 1880.

Goldmark, J., New York, N. Y. (29). Died in April, 1882.

Gould, Augustus Addison, Boston, Mass. (11). Born April 23, 1805. Died Sept. 15, 1866.

Gould, Benjamin Apthorp, Boston, Mass. (2). Born in Lancaster, Mass., June 15, 1787. Died Oct. 24, 1859.

Graham, James D., Washington, D. C. (1). Born in Virginia, 1799. Died in Boston, Mass., Dec. 28, 1865.

Gray, Alonzo, Brooklyn, N. Y. (13). Born in Townshend, Vt., Feb. 21, 1808. Died in Brooklyn, N. Y., March 10, 1860.

Gray, Asa, Cambridge, Mass. (1). Born in Paris, N. Y., Nov. 18, 1810. Died in Cambridge, Mass., Jan. 30, 1888.

Gray, James H., Springfield, Mass. (6).

Greene, Benjamin D., Boston, Mass. (1). Died Oct. 14, 1862, aged 68.

Greene, Everett W., Madison, N. J. (10). Died in 1864.

Greene, Samuel, Woonsocket, R. I. (9). Died in 1868.

Greer, James, Dayton, Ohio (20). Died in Feb., 1874.

Griffith, Robert Eglesfield, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Feb. 13, 1798. Died June 26, 1854.

Griswold, John Augustus, Troy, N. Y. (19). Born Nov. 11, 1818. Died Oct. 31, 1872.

Guest, William E., Ogdensburg, N. Y. (6).

Guyot, Arnold, Princeton, N. J. (1). Born Sept. 5, 1809. Died Feb. 8, 1884.

Habel, Louis, Northfield, Vt. (34).

Hackley, Charles William, New York, N. Y. (4). Born in Herkimer Co., N. Y., March 9, 1809. Died in New York, N. Y., January 10, 1861.

Hadley, George, Buffalo, N. Y. (6). Born June, 1813. Died Oct. 16, 1877.

Haldeman, Samuel Stehman, Chickies, Pa. (1). Born Aug. 12, 1812. Died Sept. 10, 1880.

Hale, Enoch, Boston, Mass. (1). Born in Westhampton, Mass., Jan. 29, 1790. Died in Boston, Mass., Nov. 12, 1848.

Hamilton, Jno. M., Coudersport, Pa. (33).

Hampson, Thomas, Washington, D. C. (33).

Hance, Ebenezer, Fallsington P. O., Pa. (7). Died in 1876.

Harding, Myron H., Lawrenceburg, Ind. (30.) Died Sept., 1885.

Hare, Robert, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Jan. 17, 1781. Died in Philadelphia, May 15, 1858.

Harger, Oscar, New Haven, Conn. (25). Born in Oxford, Conn., Jan. 12, 1843. Died in New Haven, Conn., Nov. 6, 1887.

Harlan, Joseph G., Haverford, Pa. (8).

Harlan, Richard, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Sept. 19, 1796. Died in New Orleans, La., Sept. 30, 1843.

Harris, Thaddeus William, Cambridge, Mass. (1). Born in Dorchester, Mass., Nov. 12, 1795. Died in Cambridge, Mass., Jan. 16, 1856.

Harrison, A. M., Plymouth, Mass. (29).

Harrison, Benjamin Franklin, Wallingford, Conn. (11). Born April 19, 1811. Died April 23, 1886.

Harrison, Jos., jr., Philadelphia, Pa. (12). Born in Philadelphia, Pa., Sept. 20, 1810. Died in Philadelphia, March 27, 1874.

Hart, Simeon, Farmington, Conn. (1). Born Nov. 17, 1795. Died April 20, 1853.

Hartt, Charles Frederick, Ithaca, N. Y. (18). Born in Nova Scotia, Aug. 20, 1840. Died March 18, 1878.

Haven, Joseph, Chicago, Ill. (17). Born in Dennis, Mass., Jan. 4, 1816. Died May 23, 1874.

Hawes, George W., Washington, D. C. (23). Born Dec. 31, 1848. Died June 22, 1882.

Hayden, Ferdinand Vandeveer, Philadelphia, Pa. (29). Born in Westfield, Mass., Sept. 7, 1829. Died Dec. 22, 1887.

Hayden, Horace H., Baltimore, Md. (1). Born in Winsor, Conn., Oct. 13, 1769. Died in Baltimore, Md., Jan. 26, 1844.

Hayes, George E., Buffalo, N. Y. (15).

Hayward, James, Boston, Mass. (1). Born in Concord, Mass., June 12, 1786. Died in Boston, Mass., July 27, 1866.

Hazen, William Babcock, Washington, D. C. (30). Born in Hartford, Vt., Sept. 27, 1830. Died Jan. 16, 1887.

Hedrick, Benjamin Sherwood, Washington, D. C. (19). Born in 1826. Died Sept. 2, 1886.

Heighway, A. E., Cincinnati, Ohio (29). Born Dec. 26, 1820. Died Jan. 24, 1888.

Hempstead, G. S. B., Portsmouth, Ohio (29). Born in 1795. Died July 9, 1883.

Henry, Joseph, Washington, D. C. (1). Born in Albany, N. Y., Dec. 17, 1797. Died May 13, 1878.

Hickox, S. V. R., Chicago, Ill. (17). Died in 1872.

Hicks, William C., New York, N. Y. (34). Died in 1885.

Hilgard, Julius Erasmus, Washington, D. C. (4). Born in Zweibrücken, Bavaria, Jan. 7, 1825. Died in Washington, D. C., May 8, 1891.

Hilgard, Theodore Charles, St. Louis, Mo. (17). Born in Zweibrücken, Bavaria, Feb. 28, 1828. Died March 5, 1875.

Hill, Walter N., Chester, Pa. (29). Born Apr. 15, 1846. Died Mar. 29, 1884.

Hincks, William, Toronto, C. W. (11). Born in 1801. Died July, 1871.

Hitchcock, Edward, Amherst, Mass. (1). Born in Deerfield, Mass., May 24, 1793. Died Feb. 27, 1864.

Hoadley, John Chipman, Boston, Mass. (29). Born Dec. 10, 1818. Died Oct. 21, 1886.
Hobbs, A. C., Bridgeport, Conn. (28). Died in Nov., 1891.
Hodgson, W. B., Savannah, Ga. (10). Born 1815.
Holbrook, John Edwards, Charleston, S. C. (1). Born in Beaufort, S. C., Dec. 30, 1796. Died in Norfolk, Mass., Sept. 8, 1871.
Holman, Mrs. S. W., Boston, Mass. (29). Died May 5, 1885.
Holmes, Edward J., Boston, Mass. (29). Died in July, 1884.
Homes, Henry A., Albany, N. Y. (11). Born in Boston, Mass., March 10, 1812. Died in Albany, N. Y., Nov. 3, 1887.
Hopkins, Albert, Williamstown, Mass. (19). Born July 14, 1807. Died May 25, 1872.
Hopkins, James G., Ogdensburg, N. Y. (10). Died in 1860.
Hopkins, T. O., Williamsville, N. Y. (10). Died in 1866.
Hopkins, Wm., Lima, N. Y. (5). Died in March, 1867.
Hoppock, Albert Eugene, Hastings-on-Hudson, N.Y. (29).
Horton, C. V. R., Chaumont, N. Y. (10). Died in 1862.
Horton, William, Craigville, N. Y. (1).
Hosford, Benj. F., Haverhill, Mass. (13). Died in 1864.
Hough, Franklin Benjamin, Lowville, N. Y. (4). Born in Martinsburgh, N. Y., July 20, 1822. Died June 11, 1885.
Houghton, Douglas, Detroit, Mich. (1). Born in Troy, N. Y., Sept. 21, 1809. Died Oct. 13, 1845.
Hovey, Edmund O., Crawfordsville, Ind. (20). Born July 15, 1801. Died March 10, 1877.
Howland, Edward Perry, Washington, D. C. (29). Born in Ledyard, N. Y., July 20, 1825. Died in Harrisburg, Pa., Sept. 12, 1888.
Hubbert, James, Richmond, Province of Quebec (16). Died in 1868.
Howland, Theodore, Buffalo, N. Y. (15).
Hunt, Edward Bissell, Washington, D. C. (2). Born in Livingston Co., N. Y., June 15, 1822. Died in Brooklyn, N. Y., Oct. 2, 1863.
Hunt, Freeman, New York, N. Y. (11). Born in Quincy, Mass., March 21, 1804. Died in Brooklyn, N. Y., March 2, 1858.
Hunt, Thomas Sterry, New York, N. Y. (1). Born in Norwich, Conn., Sept. 5, 1826. Died in New York, N. Y., Feb. 12, 1892.
Hyatt, Theodore, Chester, Pa. (30).

Ives, Moses B., Providence, R. I. (9). Died in 1857.
Ives, Thomas P., Providence, R. I. (10).

Jackson, Charles Thomas, Boston, Mass. (1). Born in Plymouth, Mass., June 21, 1805. Died Aug. 28, 1880.
James, Thomas Potts, Cambridge, Mass. (22). Born Sept. 1, 1803. Died Feb. 22, 1882.
Jeffries, John Amory, Boston, Mass. (38). Born in Milton, Mass., Sept. 2, 1859. Died in Boston, Mass., March 26, 1892.
Johnson, Hosmer A., Chicago, Ill. (17). Died in Chicago, Feb. 26, 1891.

Johnson, Walter Rogers, Washington, D. C. (1). Born in Leominster, Mass., June 21, 1794. Died April 26, 1852.

Johnson, William Schuyler, Washington, D. C. (31). Born Sept. 20, 1859. Died Oct. 6, 1883.

Jones, Catesby A. R., Washington, D. C. (8).

Jones, Henry A., Portland, Me. (29). Died Sept. 3, 1883.

Jones, James H., Boston, Mass. (28).

Joy, Charles Arad, Stockbridge, Mass. (8). Born in Ludlowville, N. Y., Oct. 8, 1823. Died in Stockbridge, Mass., May 29, 1891.

Kedzie, W. K., Oberlin, Ohio (25). Born in Kalamazoo, Mich., July 5, 1851. Died in Lansing, Mich., Apr. 10, 1880.

Keely, George W., Waterville, Me. (1). Died in 1878.

Keep, N. C., Boston, Mass. (13). Died in March, 1875.

Kennicott, Robert, West Northfield, Ill. (12). Born Nov. 13, 1835. Died in 1866.

Kerr, Washington Caruthers, Raleigh, N. C. (10). Born May 24, 1827. Died Aug. 9, 1885.

Kidder, Henry Purkitt, Boston, Mass. (29). Born Jan. 8, 1823. Died Jan. 28, 1886.

King, Mitchell, Charleston, S. C. (3). Born in Scotland, June 8, 1783. Died Nov. 12, 1862.

Kirkpatrick, James A., Philadelphia, Pa. (7). Died June 3, 1886.

Kite, Thomas, Cincinnati, Ohio (5). Died Feb. 6, 1884.

Klippart, John H., Columbus, Ohio (17). Died October, 1878.

Knickerbocker, Charles, Chicago, Ill. (17). Died in 1873.

Knight, J. B., Philadelphia, Pa. (21). Died March 10, 1879.

Lacey, O. M., Crawfordsville, Ind. (39). Died Jan. 9, 1891.

Lacklan, R., Cincinnati, Ohio (11).

Lapham, Increase Allen, Milwaukee, Wis. (3). Born in Palmyra, N. Y., March 7, 1811. Died in Oconomowoc, Wis., Sept. 14, 1875.

Larkin, Ethan Pendleton, Alfred Centre, N. Y. (33). Born Sept. 20, 1829. Died Aug. 23, 1887.

LaRoche, Réné, Philadelphia, Pa. (12). Born in Philadelphia, Pa., 1795. Died in Philadelphia, Dec., 1872.

Lasel, Edward, Williamstown, Mass. (1). Born Jan. 21, 1809. Died Jan. 31, 1852.

Lawford, Frederick, Montreal, Canada (11). Died in 1866.

Lawrence, Edward, Charlestown, Mass. (18). Born June, 1810. Died Oct. 17, 1885.

Lea, Isaac, Philadelphia, Pa. (1). Born in Wilmington, Del., March 4, 1792. Died Dec. 8, 1886.

Le Conte, John Lawrence, Philadelphia, Pa. (1). Born in New York, May 13, 1825. Died Nov. 15, 1883.

Lederer, Baron von, Washington, D. C. (1).

Leidy, Joseph, Philadelphia, Pa. (7). Born in Philadelphia, Sept. 9, 1823. Died in Philadelphia, April 30, 1891.

Leonard, Rensselaer, Mauch Chunk, Pa. (33). Born in Hancock, N. Y., April 12, 1821. Died in Mauch Chunk, Pa., Oct. 26, 1888.

Lewis, Henry Carvill, Philadelphia, Pa. (26). Born in Philadelphia, Pa., Nov. 16, 1853. Died in Manchester, England, July 21, 1888.

Libbey, Joseph, Georgetown, D. C. (31). Died July 20, 1886.

Lieber, Oscar Montgomery, Columbia, S. C. (8). Born Sept. 8, 1830. Died June 27, 1862.

Lincklaen, Ledyard, Cazenovia, N. Y. (1). Born in Cazenovia, N. Y., Oct. 17, 1820. Died April 25, 1864.

Linsley, James Harvey, Stafford, Conn. (1). Born in Northford, Conn., May 5, 1787. Died in Stratford, Conn., Dec. 26, 1843.

Lockwood, Moses B., Providence, R. I. (9). Died in 1872.

Logan, William Edmond, Montreal, Canada (1). Born in Montreal, Canada, April 23, 1798. Died in Wales, June 22, 1875.

Loiseau, Emile F., Brussels, Belgium (33). Died April 30, 1886.

Loomis, Elias, New Haven, Conn. (1). Born in Willington, Conn., Aug. 7, 1811. Died in New Haven, Conn., Aug. 15, 1889.

Loosey, Charles F., New York, N. Y. (12).

Lothrop, Joshua R., Buffalo, N. Y. (15).

Lovering, Joseph, Cambridge, Mass. (2). Born in Charlestown, Mass., Dec. 25, 1813. Died in Cambridge, Mass., Jan. 18, 1892.

Lowrie, J. R., Warriorsmark, Pa. (29). Died Dec. 10, 1885.

Lull, Edward Phelps, Washington, D. C. (28). Born Feb. 20, 1836. Died March 5, 1887.

Lyford, Moses, Springfield, Mass. (22). Born in Mt. Vernon, Me., Jan. 31, 1816. Died in Portland, Me., Aug. 4, 1887.

Lyman, Chester Smith, New Haven, Conn. (4). Born in Manchester, Conn., Jan. 13, 1814. Died in New Haven, Conn., in 1889.

Lyon, Sidney S., Jeffersonville, Ind. (20). Born Aug. 4, 1808. Died June 24, 1872.

M'Conihe, Isaac, Troy, N. Y. (5).

McCutchen, A. R., Atlanta, Ga. (25). Died Nov. 21, 1887.

McElrath, Thomas, New York, N. Y. (36). Born in Williamsport, Pa., May 1, 1807. Died in New York, N. Y., June 6, 1888.

McFadden, Thomas, Westerville, Ohio (30). Born Nov. 9, 1825. Died Nov. 9, 1883.

McFarland, Walter, New York, N. Y. (36). Died July 22, 1888.

MacGregor, Donald, Houston, Texas (33). Died in Oct., 1887.

McLachlan, J. S., Montreal, Can. (31).

McMahon, Mathew, Albany, N. Y. (11).

McNiel, John A., Binghamton, N. Y. (35). Died in Binghamton, Dec. 20, 1891, aged 75.

Maack, G. A., Cambridge, Mass. (18). Died in Aug., 1873.

Macfarlane, James, Towanda, Pa. (29). Died in 1885.

Mackintosh, James B., New York, N. Y. (27). Died in 1891.

Maffet, Wm. Ross, Wilkes Barre, Pa. (33). Died in June, 1890.

Mahan, Dennis Hart, West Point, N. Y. (9). Born in New York, N. Y., April 2, 1802. Died in New York, Sept. 16, 1871.

Marler, George L., Montreal, Can. (31).
Marsh, Dexter, Greenfield, Mass. (1). Born in Montague, Mass., Aug. 22, 1806. Died in Greenfield, Mass., April 2, 1853.
Marsh, James E., Roxbury, Mass. (10).
Martin, Benjamin Nichols, New York, N. Y. (23). Born in Mount Holly, N. J., Oct. 20, 1816. Died in New York, N. Y., Dec. 26, 1883.
Mather, William Williams, Columbus, Ohio (1). Born in Brooklyn, Conn., May 24, 1804. Died in Columbus, Ohio, Feb. 27, 1859.
Maude, John B., St. Louis, Mo. (27). Died in April, 1879.
Maupin, S., Charlottesville, Va. (10).
May, Abigail Williams, Boston, Mass. (29). Born in Boston, April 21, 1829. Died in Boston, Nov. 30, 1888.
Meade, George Gordon, Philadelphia, Pa. (15). Born Dec. 30, 1815. Died Nov. 6, 1872.
Meek, Fielding Bradford, Washington, D. C. (6). Born Dec. 10, 1817. Died Dec. 21, 1876.
Meigs, James Aitken, Philadelphia, Pa. (12). Born July 30, 1829. Died Nov. 9, 1879.
Metcalf, Caleb B., Worcester, Mass. (20). Died July 31, 1891.
Minifie, Wm., Baltimore, Md. (12). Born Aug. 14, 1805. Died Oct. 24, 1880.
Mitchel, Ormsby MacKnight, Cincinnati, Ohio (3). Born in Union Co., Ky., July 28, 1810. Died in Beaufort, S. C., Oct. 30, 1862.
Mitchell, Miss Maria, Lynn, Mass. (4). Born in Nantucket, Mass., Aug. 1, 1818. Died in Lynn, 1889.
Mitchell, William, Poughkeepsie, N. Y. (2). Born in Nantucket, Mass., Dec. 20, 1791. Died in Poughkeepsie, N. Y., April 19, 1868.
Mitchell, Wm. H., Florence, Ala. (17).
Monroe, Nathan, Bradford, Mass. (6). Born in Minot, Me., May 16, 1804. Died in Bradford, Mass., July 8, 1866.
Monroe, William, Concord, Mass. (18). Died April 27, 1877.
Moore, E. C., New York, N. Y. (30).
Morgan, Lewis Henry, Rochester, N. Y. (10). Born near Aurora, N. Y., Nov. 21, 1818. Died Dec. 17, 1881.
Morgan, Mrs. Mary E., Rochester, N. Y. (31). Died in 1884.
Morison, N. H., Baltimore, Md, (17). Born in 1815. Died Nov. 14, 1890.
Morris, John B., Nashville, Tenn. (26).
Morris, Wistar, Philadelphia, Pa. (33). Died March 23, 1891.
Morton, Samuel George, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Jan. 26, 1799. Died in Philadelphia, May 15, 1851.
Mott, Alexander B., New York, N. Y. (36). Died Aug. 12, 1889.
Mudge, Benjamin Franklin, Manhattan, Kansas (25). Born in Orrington, Me., Aug. 11, 1817. Died Nov. 21, 1879.
Muir, William, Montreal, Can. (31). Died July, 1885.
Mussey, William Heberdom, Cincinnati, Ohio (30). Born Sept. 30, 1818. Died Aug. 1, 1882.

Nagel, Herman, St. Louis, Mo. (30). Born in Tritzwalk, Germany, May 28, 1820. Died in St. Louis, Mo., Feb. 18, 1889.

Newland, John, Saratoga Springs, N. Y. (28). Died Jan. 18, 1880.
Newton, E. H., Cambridge, N. Y. (1).
Nichols, Charles A., Providence, R. I. (17). Born Jan. 4, 1826. Died Oct. 20, 1877.
Nichols, William Ripley, Boston, Mass. (18). Born April 30, 1847. Died July 14, 1886.
Nicholson, Thomas, New Orleans, La. (21).
Nicollet, Jean Nicholas, Washington, D. C. (1). Born in Savoy, France, July 24, 1786. Died in Washington, D. C., Sept. 11, 1843.
Northrop, John I., New York, N. Y. (36).
Norton, John Pitkin, New Haven, Conn. (1). Born July 19, 1822. Died Sept. 5, 1852.
Norton, William Augustus, New Haven, Conn. (6). Born in East Bloomfield, N. Y., Oct. 25, 1810. Died Sept. 21, 1883.
Noyes, James Oscar, New Orleans, La. (21). Born in Niles, N. Y., June 14, 1829. Died in New Orleans, La., Sept. 11, 1872.
Nutt, Cyrus, Bloomington, Ind. (20). Born in Trumbull Co., Ohio, Sept. 4, 1814. Died in Bloomington, Aug. 23, 1875.

Oakes, Wm., Ipswich, Mass. (1). Born July 1, 1799. Died July 31, 1848.
Ogden, Robert W., New Orleans, La. (21). Died March 24, 1878.
Ogden, William Butler, High Bridge, N. Y. (17). Born in New York, N. Y., 1805. Died in New York, Aug. 3, 1877.
Oliver, Miss Mary E., Ithaca, N. Y. (20).
Olmsted, Alexander Fisher, New Haven, Conn. (4). Born Dec. 20, 1822. Died May 5, 1853.
Olmsted, Denison, New Haven, Conn. (1). Born in East Hartford, Conn., June 18, 1791. Died in New Haven, Conn., May 13, 1859.
Olmsted, Denison, jr., New Haven, Conn. (1). Born Feb. 16, 1824. Died Aug. 15, 1846.
Orton, James, Poughkeepsie, N. Y. (18). Born in Seneca Falls, N. Y., April 21, 1830. Died in Peru, S. A., Sept. 24, 1877.
Osbun, Isaac J., Salem, Mass. (29).
Otis, George Alexander, Washington, D. C. (10). Born in Boston, Mass., Nov. 12, 1830. Died Feb. 23, 1881.
Owen, Richard, New Harmony, Ind. (20). Born in Scotland, Jan. 6, 1810. Died in New Harmony, March 24, 1890.

Packer, Harry E., Mauch Chunk, Pa. (30). Died Feb. 1, 1884.
Painter, Jacob, Lima, Pa. (23). Died in 1876.
Painter, Minshall, Lima, Pa. (7).
Parker, Wilbur F., West Meriden, Conn. (23). Died in 1876.
Parkman, Samuel, Boston, Mass. (1). Born in 1816. Died Dec. 15, 1854.
Parry, Charles C., Davenport, Iowa (6). Born in Admington, Worcestershire, Eng., Aug. 28, 1823. Died in Davenport, Iowa, Feb. 20, 1890.
Parsons, Henry Betts, New York, N. Y. (30). Born Nov. 20, 1855. Died Aug. 21, 1885.

Payn, Charles H., Saratoga Springs, N. Y. (28). Born May 16, 1814. Died Dec. 20, 1881.

Pearson, H. G., New York, N. Y. (36).

Pease, F. S., Buffalo, N. Y. (35). Died Nov. 6, 1890.

Pease, Rufus D., Philadelphia, Pa. (33). Died in 1890.

Peirce, Benjamin Osgood, Beverly, Mass. (18). Born in Beverly, Sept. 26, 1812. Died in Beverly, Nov. 12, 1883.

Peirce, Benjamin, Cambridge, Mass. (1). Born in Salem, Mass., April 4, 1809. Died in Cambridge, Mass., Oct. 6, 1880.

Perch, Bernard, Frankford, Pa. (35). Born in 1850. Died in 1887.

Perkins, George Roberts, Utica, N. Y. (1). Born in Otsego Co., N. Y., May 3, 1812. Died in New Hartford, N. Y., Aug. 22, 1876.

Perkins, Henry C., Newburyport, Mass. (18). Born Nov. 13, 1804. Died Feb. 2, 1873.

Perry, John B., Cambridge, Mass. (16). Born in 1820. Died Oct. 3, 1872.

Perry, Matthew Calbraith, New York, N. Y. (10). Born in South Kingston, R. I., 1795. Died in New York, March 4, 1858.

Phelps, Mrs. Almira Hart Lincoln, Baltimore, Md. (13). Born in Berlin, Conn., July 15, 1793. Died in Berlin, July 15, 1884.

Philbrick, Edw. S., Brookline, Mass. (29). Born in Boston, Mass., Nov. 20, 1827. Died in Brookline, Mass., Feb. 13, 1889.

Phillips, John C., Boston, Mass. (29). Born in 1839. Died Mar. 1, 1885.

Piggot, A. Snowden, Baltimore, Md. (10).

Pim, Bedford Clapperton Trevelyan, London, Eng. (33). Born in England, June 12, 1826. Died Oct., 1886.

Platt, W. G., Philadelphia, Pa. (32). Died Nov., 1885.

Plumb, Ovid, Salisbury, Conn. (9).

Pope, Charles Alexander, St. Louis, Mo. (12). Born in Huntsville, Ala., March 15, 1818. Died in Paris, Mo., July 6, 1870.

Porter, John Addison, New Haven, Conn. (14). Born in Catskill, N. Y., March 15, 1822. Died in New Haven, Conn., Aug. 25, 1866.

Potter, Stephen H., Hamilton, Ohio (30). Born Nov. 10, 1812. Died Dec. 9, 1883.

Pourtalès, Louis François de, Cambridge, Mass. (1). Born March 4, 1824. Died July 19, 1880.

Pruyn, John Van Schaick Lansing, Albany, N. Y. (1). Born in Albany, N. Y., June 22, 1811. Died in Clifton Springs, N. Y., Nov. 21, 1877.

Pugh, Evan, Centre Co., Pa. (14). Born Feb. 29, 1828. Died April 29, 1864.

Pulsifer, Sidney, Philadelphia, Pa. (21). Died March 24, 1884.

Putnam, Mrs. Frederick Ward, Cambridge, Mass. (19). Born in Charlestown, Mass., Dec. 29, 1838. Died in Cambridge, Mass., March 10, 1879.

Putnam, J. Duncan, Davenport, Iowa (27). Born Oct. 18, 1855. Died Dec. 10, 1881.

Read, Ezra, Terre Haute, Ind. (20). Died in 1877.

Redfield, William C., New York, N. Y. (1). Born near Middletown, Conn., March 26, 1789. Died Feb. 12, 1857.

Resor, Jacob, Cincinnati, Ohio (8). Died in 1871.

Robb, James, Fredericton, N. B. (4).

Robinson, Coleman T., Buffalo, N. Y. (15). Born in Putnam Co., N. Y., in 1838. Died near Brewster's Station, N. Y., May 1, 1872.

Rochester, Thomas Fortescue, Buffalo, N. Y. (35). Born Oct. 8, 1823. Died May 24, 1887.

Rockwell, John Arnold, Norwich, Conn. (10). Born in Norwich, Conn., August 27, 1803. Died in Washington, D. C., February 10, 1861.

Roeder, F. A., Cincinnati, Ohio (30).

Rogers, Henry Darwin, Glasgow, Scotland (1). Born in Philadelphia, Pa. Aug. 1, 1808. Died in Glasgow, Scotland, May 29, 1866.

Rogers, James Blythe, Philadelphia, Pa. (1). Born in Philadelphia, Pa., Feb. 11, 1802. Died in Philadelphia, June 15, 1852.

Rogers, Robert Empie, Philadelphia, Pa. (18). Born in Baltimore, Md., March 29, 1813. Died Sept. 6, 1884.

Rogers, William Barton, Boston, Mass. (1). Born in Philadelphia, Pa., Dec. 7, 1804. Died in Boston, May 30, 1882.

Root, Elihu, Amherst, Mass. (25). Born Sept. 14, 1845.

Sager, Abram, Ann Arbor, Mich. (6). Born in Bethlehem, N. Y., Dec. 22, 1811. Died in Ann Arbor, Mich., August 6, 1877.

Sanders, Benjamin D., Wellsburg, W. Va. (19).

Scammon, Jonathan Young, Chicago, Ill. (17). Born in Whitefield, Me., in 1812. Died in Chicago, Ill., March 17, 1890.

Schaeffer, Geo. C., Washington, D. C. (1). Died in 1873.

Schimpff, Robert D., Scranton, Pa. (36).

Schley, William, New York, N. Y. (28). Died in 1882.

Schram, Nicholas Hallock, Newburgh, N. Y. (33). Died in Newburgh, N. Y., aged 54 years, 1 month and 2 days.

Schrenk, Joseph, Hoboken, N. J. (36).

Scott, Joseph, Dunham, C. E. (11). Died in 1865.

Seaman, Ezra Champion, Ann Arbor, Mich. (20). Born Oct. 14, 1805. Died July 15, 1880.

Sênecal, L. A., Montreal, Can. (31).

Senter, Harvey S., Aledo, Ill. (20). Died in 1875.

Seward, William Henry, Auburn, N. Y. (1). Born in Florida, N. Y., May 16, 1801. Died in Auburn, N. Y., Oct. 10, 1872.

Sheafer, Peter W., Pottsville, Pa. (4). Died March 26, 1891.

Sheppard, William, Drummondville, Province of Quebec, Can. (11). Born in 1783. Died in 1867.

Sherwin, Thomas, Dedham, Mass. (11). Born in Westmoreland, N. H., March 26, 1799. Died in Dedham, Mass., July 23, 1869.

Sill, Elisha N., Cuyahoga Falls, Ohio (6). Born in 1801. Died April 26, 1888.

Silliman, Benjamin, New Haven, Conn. (1). Born in North Stratford, Conn., August 8, 1779. Died in New Haven, Conn., Nov. 22, 1864.

Silliman, Benjamin, New Haven, Conn. (1). Born in New Haven, Conn., Dec. 4, 1816. Died Jan. 14, 1885.

Simpson, Edward, Washington, D. C. (28). Born in New York, N. Y., March 3, 1824. Died in Washington, D. C., Dec. 1, 1888.

Skinner, George, Kalida, Ohio (33).

Skinner, John B., Buffalo, N. Y. (15). Died in 1871.

Slack, J. H., Philadelphia, Pa. (12).

Smith, Charles A., St. Louis, Mo. (27). Died in 1884.

Smith, David P., Springfield, Mass. (29). Born Oct. 1, 1830. Died Dec. 26, 1880.

Smith, Mrs. Erminnie Adelle, Jersey City, N. J. (25). Born April 26, 1836. Died June 9, 1886.

Smith, John Lawrence, Louisville, Ky. (1). Born near Charleston, S. C., Dec. 17, 1818. Died Oct. 12, 1883.

Smith, J. V., Cincinnati, Ohio (5).

Smith, James Young, Providence, R. I. (9). Born in Groton, Conn., Sept. 15, 1809. Died March 26, 1876.

Smith, Lyndon Arnold, Newark, N. J. (9). Born in Haverhill, N. H., November 11, 1795. Died in Newark, N. J., December 15, 1865.

Snell, Ebenezer Strong, Amherst, Mass. (2). Born in North Brookfield, Mass., October 7, 1801. Died in Amherst, Mass., Sept., 1877.

Sparks, Jared, Cambridge, Mass. (2). Born in Willington, Conn., May 10, 1819. Died in Cambridge, Mass., March 14, 1866.

Spinzig, Charles, St. Louis, Mo. (27). Died Jan. 22, 1882.

Squier, Ephraim George, New York, N. Y. (18). Born in Bethlehem, N. Y., June 17, 1821. Died in Brooklyn, N. Y., April 17, 1888.

Stearns, Josiah A., Boston, Mass. (29).

Stearns, Silas, Pensacola, Fla. (28). Died Aug. 2, 1888.

Steele, Joel Dorman, Elmira, N. Y. (33). Born in Lima, N. Y., May 14, 1836. Died May 25, 1886.

Steiner, Lewis H., Baltimore, Md. (7). Born in Frederick City, Md., in 1827.

Stevenson, James, Washington, D. C. (29). Born in Maysville, Ky., Dec. 24, 1840. Died in New York, N. Y., July 25, 1888.

Stimpson, Wm., Chicago, Ill. (12). Born Feb. 14, 1832. Died May 26, 1872.

Stone, Leander, Chicago, Ill. (32). Died April 2, 1888.

Stone, Samuel, Chicago, Ill. (17). Born Dec. 6, 1798. Died May 4, 1876.

St. John, Joseph S., Albany, N. Y. (28). Died Nov. 23, 1882.

Straight, H. H., Chicago, Ill. (25). Died Nov. 17, 1886.

Sturges, George, Chicago, Ill. (37). Born at Putnam, Ohio, May 13, 1838. Died at Lake Geneva, Wis., Aug. 12, 1890.

Sullivan, Algernon Sidney, New York, N. Y. (36). Born April 5, 1826. Died Dec. 4, 1887.

Sullivant, William Starling, Columbus, Ohio (7). Born near Columbus, O., Jan 15, 1803. Died in Columbus, O., April 30, 1873.

Sutton, George, Aurora, Ind. (20). Died June 13, 1886.

Swain, James, Fort Dodge, Iowa (21). Born in 1816. Died in 1877.

Tallmadge, James, New York, N. Y. (1). Born in Stamford, N. Y., Jan. 20, 1778. Died in New York, N. Y., Oct. 3, 1853.

Taylor, Arthur F., Cleveland, Ohio (29). Born Dec. 10, 1853. Died June 28, 1883.

Taylor, Richard Cowling, Philadelphia, Pa. (1). Born in England, Jan. 18, 1789. Died in Philadelphia, Pa., November 26, 1851.

Taylor, Robert N., Tollesboro, Ky. (37). Died Aug. 13, 1888.

Tenney, Sanborn, Williamstown, Mass. (17). Born in January, 1827. Died July 11, 1877.

Teschemacher, James Englehert, Boston, Mass. (1). Born in Nottingham, England, June 11, 1790. Died near Boston, Nov. 9, 1853.

Thompson, A. Remsen, New York, N. Y. (1). Died in Oct., 1879.

Thompson, Alexander, Aurora, N. Y. (1).

Thompson, Charles Oliver, Terre Haute, Ind. (29). Born in East Windsor Hill, Conn., Sept. 25, 1835. Died in Terre Haute, Ind., March 17, 1885.

Thompson, Zadock, Burlington, Vt. (1). Born in Bridgewater, Vt., May 23, 1796. Died in Burlington, Vt., Jan 19, 1856.

Thomson, Henry R., Crawfordsville, Ind. (30). Died in 1884.

Thurber, Isaac, Providence, R. I. (9).

Tileman, John Nicholas, Sandy, Utah (33). Born in Horhun, Denmark, March 28, 1845. Died in Salt Lake City, Utah, Sept. 4, 1888.

Tillman, Samuel Dyer, Jersey City, N. J. (15). Born April, 1815. Died Sept. 4, 1875.

Tobin, Thomas W., Louisville, Ky. (30). Died Aug. 4, 1883.

Todd, Albert, St. Louis, Mo. (27). Born March 4, 1813. Died April 30, 1885.

Tolderoy, James B., Fredericton, N. B. (11).

Torrey, John, New York, N. Y. (1). Born in New York, N. Y., Aug. 15, 1796. Died in New York, March 10, 1873.

Torrey, Joseph, Burlington, Vt. (2). Born in Rowley, Mass., Feb. 2, 1797. Died in Burlington, Vt., Nov. 26, 1867.

Totten, Joseph Gilbert, Washington, D. C. (1). Born in New Haven, Conn., August 23, 1788. Died in Washington, D. C., April 22, 1864.

Townsend, Howard, Albany, N. Y. (10). Born Nov. 22, 1823. Died Jan. 6, 1867.

Townsend, John Kirk, Philadelphia, Pa. (1). Born Aug. 10, 1809. Died Feb. 16, 1851.

Townsend, Robert, Albany, N. Y. (9). Born 1799. Died Aug. 15, 1866.

Trembley, J. B., Oakland, Cal. (17).

Troost, Gerard, Nashville, Tenn. (1). Born in Bois-le-Duc, Holland, March 15, 1776. Died in Nashville, Tenn., Aug. 14, 1850.

Tuomey, Michael, Tuscaloosa, Ala. (1). Born in Ireland, September 29, 1805. Died in Tuscaloosa, Ala., March 20, 1857.

Tupper, Samuel Y., Charleston, S. C. (38). Died in 1891.

Tweedale, John B., St. Thomas, Can. (35). Born in Ormskirk, Lancashire, Eng., Oct. 16, 1821. Died in St. Thomas, Can., Nov. 18, 1889.

Tyler, Edward R., New Haven, Conn. (1). Born Aug. 3, 1800. Died Sept. 28, 1848.

Tyler, Edward R., Washington. D. C. (31). Died in Washington, March 30, 1891.

Vancleve, John W., Dayton, Ohio (1).

Vanuxem, Lardner, Bristol, Pa. (1). Born in Philadelphia, Pa., July 23, 1792. Died in Bristol, Pa., June 25, 1848.

Vaux, William Sanson, Philadelphia, Pa. (1). Born in Philadelphia, May 19, 1811. Died in Philadelphia, May 5, 1882.

Wadsworth, James Samuel, Genesee, N. Y. (2). Born in Geneseo, N. Y., October 30, 1807. Died near Chancellorville, Va., May 8, 1864.

Wagner, Tobias, Philadelphia, Pa. (9).

Walker, J. R., Bay Saint Louis, Miss. (19). Born Aug. 7, 1830. Died June 22, 1887.

Walker, Joseph, Oxford, N. Y. (10).

Walker, Sears C., Washington, D. C. (1). Born March 28, 1805. Died January 30, 1853.

Walker, Timothy, Cincinnati, Ohio (4). Born in Wilmington, Mass., Dec. 1, 1802. Died in Cincinnati, Ohio, Jan. 15, 1856.

Walling, H. F., Cambridge, Mass. (16). Died April 8, 1888.

Walsh, Benjamin D., Rock Island, Ill. (17). Born in Frome, England, Sept. 21, 1808. Died in Rock Island, Ill., Nov. 18, 1869.

Walton, Joseph J., Philadelphia, Pa. (29). Born in Barnesville, Ohio, Nov. 1, 1855. Died in Philadelphia, Pa., Oct. 11, 1889.

Wanzer, Ira, Brookfield, Conn. (18). Born in New Fairfield, Conn., April 17, 1796. Died in New Milford, Conn., March 5, 1879.

Warnecke, Carl, Montreal, Can. (31). Died May 14, 1886.

Warren, Geo. Washington, Boston, Mass. (18). Died in 1884.

Warren, Gouverneur Kemble, Newport, R. I. (12). Born in Cold Spring N. Y., Jan. 8, 1830. Died in Newport, R. I., Aug. 8, 1882.

Warren, John Collins, Boston, Mass. (1). Born in Boston, Mass., Aug. 1, 1778. Died in Boston, May 4, 1856.

Warren, Samuel D., Boston, Mass. (29). Born in 1817. Died May 11, 1888.

Watertown, Charles, Wakefield, Eng. (1). Born in Wakefield, England. Died in Wakefield, May 26, 1865.

Watkins, Samuel, Nashville, Tenn. (26).

Watson, James Craig, Ann Arbor, Mich. (13). Born in Fingal, Canada, Jan. 28, 1838. Died in Madison, Wis., Nov. 23, 1880.

Watson, Sereno, Cambridge, Mass. (22). Died March 9, 1892, in the 66th year of his age.

Webster, Horace B., Albany, N. Y. (1). Born in 1812. Died Dec. 8, 1843.

Webster, J. W., Cambridge, Mass. (1). Born in 1793. Died Aug. 30, 1850.

Webster, M. H., Albany, N. Y. (1).

Weed, Monroe, Wyoming, N. Y. (6). Died in 1867.

Welch, Mrs. G. O., Lynn, Mass. (21). Died in June, 1882.

Welsh, John, Philadelphia, Pa. (33). Died May, 1886.

Weyman, George W., Pittsburgh, Pa. (6). Born April, 1832. Died July 16, 1864.

Wheatland, Richard H., Salem, Mass. (13). Born July 6, 1830. Died Dec. 21, 1863.

Wheatley, Charles M., Phœnixville, Pa. (1). Died May 6, 1882.

Wheeler, Arthur W., Baltimore, Md. (29). Born in March, 1859. Died Jan. 6, 1881.

Wheildon, William W., Concord, Mass. (13). Born in 1805. Died in Concord, Mass., Jan. 7, 1892.

Whitall, Henry, Camden, N. J. (33).

White, Samuel S., Philadelphia, Pa. (23). Died Dec. 30, 1879.

Whiting, Lewis E., Saratoga Springs, N. Y. (28). Born March 7, 1815. Died Aug. 2, 1882.

Whitman, Edmund B., Cambridge, Mass. (29). Died Sept. 2, 1883.

Whitman, Wm. E., Philadelphia, Pa. (23). Died in 1875.

Whitney, Asa, Philadelphia, Pa. (1). Born Dec. 1, 1791. Died June 4, 1874.

Whittlesey, Charles, Cleveland, Ohio (1). Born in Southington, Conn., Oct. 5, 1808. Died Oct. 18, 1886.

Whittlesey, Charles C., St. Louis, Mo. (11). Died in 1872.

Wight, Orlando W., Detroit, Mich. (34).

Wilber, G. M., Pine Plains, N. Y. (19).

Wilder, Graham, Louisville, Ky. (30). Born July 1, 1843. Died Jan. 16, 1885.

Willard, Emma C. Hart, Troy, N. Y. (15). Born in Berlin, Conn., Feb. 23, 1787. Died in Troy, N. Y., April 15, 1870.

Williams, Frank, Buffalo, N. Y. (25). Died Aug. 13, 1884.

Williams, P. O., Watertown, N. Y. (24).

Williamson, Robert S., San Francisco, Cal. (12). Born in New York about 1825.

Wilson, C. H., Belize, British Honduras (30).

Wilson, Mrs. Mary V. C., Mobile, Ala. (37). Born in Morengo County, Ala., Jan. 29, 1840. Died near Tullahoma, Tenn., June 24, 1889.

Wilson, W. C., Carlisle, Pa. (12).

Winchell, Alexander, Ann Arbor, Mich. (3). Born in North East, N. Y., Dec. 31, 1824. Died in Ann Arbor, Mich., Feb. 19, 1891.

Winlock, Joseph, Cambridge, Mass. (5). Born in Shelbyville, Ky., Feb. 6, 1826. Died in Cambridge, Mass., June 11, 1875.

Woerd, Chas. Vander, Waltham, Mass. (29). Born in Leyden, Holland, Oct. 6, 1821. Died near Dagget, Cal., Dec. 29, 1888.

Woodbury, Levi, Portsmouth, N. H. (1). Born in Francistown, N. H., Dec. 22, 1789. Died Sept. 4, 1851.

Woodman, John Smith, Hanover, N. H. (11). Born in Durham, N. H., Sept. 6, 1819. Died in Durham, N. H., May 15, 1871.

Woodward, A. E., Jefferson City, Mo. (39). Died in Montana, Sept. 20, 1891.

Woodward, Joseph Janvier, Washington, D. C. (28). Born in Philadelphia, Pa., Oct. 30, 1833. Died near that city, Aug. 17, 1884.

Worthen, Amos Henry, Springfield, Ill. (5). Born Oct. 31, 1813. Died May 6, 1888.

Worthington, George, New York, N. Y. (36). Died Feb. 1, 1892.

Wright, Elizur, Boston, Mass. (31). Born in South Canaan, Conn., Feb. 12, 1804. Died Nov. 20, 1885.

Wright, Harrison, Wilkes Barre, Pa. (29). Born July 15, 1850. Died Feb. 20, 1885.

Wright, John, Troy, N. Y. (1).

Wyman, Jeffries, Cambridge, Mass. (1). Born in Chelmsford, Mass., Aug. 11, 1814. Died in Bethlehem, N. H., Sept. 4, 1874.

Wyckoff, William Cornelius, New York, N. Y. (20). Born in New York, N. Y., May 28, 1832. Died in Brooklyn, N. Y., May 2, 1888.

Yarnall, M., Washington, D. C. (26). Born in 1817. Died Jan. 27, 1879.

Youmans, Edward Livingston, New York, N. Y. (6). Born in Coeymans, N. Y., June 3, 1821. Died Jan. 18, 1887.

Young, Ira, Hanover, N. H. (1). Born in Lebanon, N. H., May 23, 1801. Died in Hanover, N. H., Sept. 14, 1858.

Zentmayer, Joseph, Philadelphia, Pa. (29). Died, 1887.

ADDRESS

BY

GEORGE LINCOLN GOODALE.

USEFUL PLANTS OF THE FUTURE. — SOME OF THE POSSIBILITIES OF ECONOMIC BOTANY.

Our Association demands of its president, on his retirement from office, some account of matters connected with the department of science in which he is engaged.

But you will naturally expect that, before I enter upon the discharge of this duty, I should present a report respecting the mission with which you entrusted me last year. You desired me to attend the annual meeting of the Australasian Association for the Advancement of Science, and express your good wishes for its success. Compliance with your request did not necessitate any material change in plans formed long ago to visit the South Seas; some of the dates and the sequence of places had to be modified; otherwise the early plans were fully carried out.

I can assure you that it seemed very strange to reverse the seasons, and find mid-summer in January. But in the meeting with our brethren of the southern hemisphere, nothing else was reversed. The official welcome to your representative was as cordial, and the response by the members was as kindly as that which the people in the northern hemisphere would give to any fellow-worker coming from beyond the sea.

The meeting to which I was commissioned was held in January last in the Cathedral city of Christchurch, New Zealand, the seat of Canterbury College.

Considering the distance between the other colonies and New Zealand, the meeting was well attended. From Hobart, Tasmania,

to the southern harbor, known as the Bluff, in New Zealand, the sea voyage is only a little short of one thousand miles of rough water. From Sydney in New South Wales to Auckland, New Zealand, it is over twelve hundred miles. If, therefore, one journeys from Adelaide in South Australia, to Christchurch, New Zealand, where the meeting was held, he travels by land and by sea over two thousand miles. From Brisbane in Queensland, it is somewhat farther. Although certain concessions are made to the members of the Association, the fares by rail and by steamship are high, so that a journey from any one of the seats of learning in Australia proper to New Zealand is formidable on account of its cost. It is remarkable that so large a number of members should have met together under such circumstances, and it speaks well for the great strength and vigor of the Association.

The Australasian Association is modelled rather more closely after the British Association than is our own. The president delivers his address upon his inauguration. There are no general business meetings, but all the details are attended to by an executive committee answering to our council; none except the members and associates are invited to attend even the sectional meetings and there are some other differences between the three associations. The secretaries stated to me their conviction that their organization and methods are better adapted to their surroundings than ours would be, and all of their arguments seemed cogent. Although the Association has been in existence but three years, it has accomplished great good. It has brought together workers in different fields for conference and mutual benefit; it has diminished misunderstandings, and has strengthened friendships. In short, it is doing the same kind of good work that we believe ours is now doing, and in much the same way.

Your message was delivered at the general evening session immediately before the induction of the new officers. The retiring president, Baron von Mueller, and the incoming president Sir James Hector, in welcoming your representative, expressed their pleasure that you should have seen fit to send personal greetings.

In replying to their welcome, I endeavored to convey your felicitations upon the pronounced success of the Association, and your best wishes for a prosperous future. In your name, I extended a cordial invitation to the members to gratify us by their presence at some of our annual meetings, and I have good reasons to believe

that this invitation will be accepted. I know it will be most thoroughly and hospitably honored by us.

On the morning of the session to which I refer we received, in the daily papers, a cable telegram relative to the Bering Sea difficulties (which were then in an acute stage). In your stead, I ventured to say, "In these days of disquieting despatches, when there are rumors of trouble between Great Britain and the United States, it is pleasant to think that 'blood is thicker than water.'" This utterance was taken to mean that we are all English-speaking kinsmen; and even before I had finished, the old proverb was received with prolonged applause.

The next meeting of the Australasian Association is to be held in Hobart, the capital of Tasmania, under the presidency of the governor, Sir Robert Hamilton. The energetic secretaries Professor Liversidge, Professor Hutton and Mr. Morton, promise a cordial welcome to any of our members visiting the Association. Should you accept the invitation, you will enjoy every feature of the remarkable island, Tasmania, where the meeting is to be held. You will be delighted by Tasmanian scenery, vegetation and climate, but that which will give you the greatest enjoyment in this as in other English South-Sea colonies, is the fact that you are among English-speaking friends half way round the world. You will find that their efficient Association is devoted to the advancement of science and the promotion of sound learning. In short you will be made to feel at home.

The subject which I have selected for the valedictory address deals with certain industrial, commercial and economic questions: nevertheless it lies wholly within the domain of botany. I invite you to examine with me some of the possibilities of economic botany.

Of course, when treating a topic which is so largely speculative as this, it is difficult and unwise to draw a hard and fast line between possibilities and probabilities. Nowadays, possibilities are so often realized rapidly that they become accomplished facts before we are aware.

In asking what are the possibilities that other plants than those we now use may be utilized we enter upon a many-sided inquiry.0* Speculation is rife as to the coming man. May we not ask what plants the coming man will use.

There is an enormous disproportion between the total number of

*For references, notes, etc., see p. 33.

species of plants known to botanical science and the number of those which are employed by man.

The species of flowering plants already described and named are about one hundred and seven thousand. Acquisitions from unexplored or imperfectly explored regions may increase the aggregate perhaps one-tenth, so that we are within very safe limits in taking the number of existing species to be somewhat above one hundred and ten thousand.[1]

Now if we should make a comprehensive list of all the flowering plants which are cultivated on what we may call a fairly large scale at the present day, placing therein all food[2] and forage plants, all those which are grown for timber and cabinet woods, for fibers and cordage, for tanning materials, dyes, resins, rubber, gums, oils, perfumes and medicines, we could bring together barely three hundred species. If we should add to this short catalogue all the species, which, without cultivation, can be used by man, we should find it considerably lengthened. A great many products of the classes just referred to are derived in commerce from wild plants, but exactly how much their addition would extend the list, it is impossible in the present state of knowledge to determine. Every enumeration of this character is likely to contain errors from two sources: first, it would be sure to contain some species which have outlived their real usefulness, and, secondly, owing to the chaotic condition of the literature of the subject, omissions would occur.

But after all proper exclusions and additions have been made, the total number of species of flowering plants utilized to any considerable extent by man in his civilized state does not exceed, in fact it does not quite reach, one per cent.

The disproportion between the plants which are known and those which are used becomes much greater when we take into account the species of flowerless plants also. Of the five hundred ferns and their allies we employ for other than decorative purposes only five; the mosses and liverworts, roughly estimated at five hundred species, have only four which are directly used by man. There are comparatively few algæ, fungi, or lichens which have extended use.

Therefore, when we take the flowering and flowerless together, the percentage of utilized plants falls far below the estimate made for the flowering alone.

Such a ratio between the number of species known and the num-

ber used justifies the inquiry which I have proposed for discussion at this time—namely, can the short list of useful plants be increased to advantage? If so, how?

This is a practical question; it is likewise a very old one. In one form or another, by one people or another, it has been asked from early times. In the dawn of civilization, mankind inherited from savage ancestors certain plants, which had been found amenable to simple cultivation, and the products of these plants supplemented the spoils of the chase and of the sea. The question which we ask now was asked then. Wild plants were examined for new uses; primitive agriculture and horticulture extended their bounds in answer to this inquiry. Age after age has added slowly and cautiously to the list of cultivable and utilizable plants, but the aggregate additions have been, as we have seen, comparatively slight.

The question has thus no charm of novelty, but it is as practical to-day as in early ages. In fact, at the present time, in view of all the appliances at the command of modern science and under the strong light cast by recent biological and technological research, the inquiry which we propose assumes great importance. One phase of it is being attentively and systematically regarded in the great experiment stations, another phase is being studied in the laboratories of Chemistry and Pharmacy, while still another presents itself in the museums of Economic Botany.

Our question may be put in other words, which are even more practical. What present likelihood is there that our tables may, one of these days, have other vegetables, fruits and cereals, than those which we now use? What chance is there that new fibers may supplement or even replace those which we spin and weave, that woven fabrics may take on new vegetable colors, that flowers and leaves may yield new perfumes and flavors? What probability is there that new remedial agents may be found among plants neglected or wholly unknown? The answer which I shall attempt is not in the nature of a prophecy; it can claim no rank higher than that of a reasonable conjecture.

At the outset it must be said that synthetic chemistry has made and is making some exceedingly short cuts across this field of research, giving us artificial dyes, odors, flavors and medicinal substances, of such excellence that it sometimes seems as if before long the old-fashioned chemical processes in the plant itself would

play only a subordinate part. But although there is no telling where the triumphs of chemical synthesis will end, it is not probable that it will ever interfere essentially with certain classes of economic plants. It is impossible to conceive of a synthetic fiber or a synthetic fruit. Chemistry gives us fruit-ethers and fruit-acids, and after a while may provide us with a true artificial sugar and amorphous starch; but artificial fruits worth the eating or artificial fibers worth the spinning are not coming in our day.

Despite the extraordinary achievements of synthetic chemistry, the world must be content to accept for a long time to come the results of the intelligent labor of the cultivator of the soil and the explorer of the forest. Improvement of the good plants we now utilize, and the discovery of new ones must remain the care of large numbers of diligent students and assiduous workmen. So that, in fact, our question resolves itself into this: can these practical investigators hope to make any substantial advance?

It will be well to glance first at the manner in which our wild and cultivated plants have been singled out for use. We shall, in the case of each class, allude to the methods by which the selected plants have been improved, or their products fully utilized. Thus looking the ground over, although not minutely, we can see what new plants are likely to be added to our list. Our illustrations can, at the best, be only fragmentary.

We shall not have time to treat the different divisions of the subject in precisely the proportions which would be demanded by an exhaustive essay; an address on an occasion like this must pass lightly over some matters which other opportunities for discussion could properly examine with great fulness. Unfortunately, some of the minor topics which must be thus passed by, possess considerable popular interest; one of these is the first subordinate question introductory to our task, namely, how were our useful cultivated and wild plants selected for use?

A study of the early history of plants employed for ceremonial purposes, in religious solemnities, in incantations, and for medicinal uses, shows how slender has sometimes been the claim of certain plants to the possession of any real utility. But some of the plants which have been brought to notice in these ways have afterwards been found to be utilizable in some fashion or other. This is often seen in the cases of the plants which have been suggested for medicinal use through the absurd doctrine of signatures.[3]

It seems clear that, except in modern times, useful plants have been selected almost wholly by chance, and it may well be said that a selection by accident is no selection at all. Nowadays, the new selections are based on analogy. One of the most striking illustrations of the modern method is afforded by the utilization of bamboo fiber for electric lamps.

Some of the classes of useful plants must be passed by without present discussion, others alluded to slightly, while still other groups fairly representative of selection and improvement will be more fully described. In this latter class would naturally come, of course, the food-plants known as

I. THE CEREALS.

Let us look first at these.

The species of grasses which yield these seed-like fruits, or as we might call them for our purpose seeds, are numerous;[4] twenty of them are cultivated largely in the Old World, but only six of them are likely to be very familiar to you, namely, wheat, rice, barley, oats, rye and maize. The last of these is of American origin, despite doubts which have been cast upon it. It was not known in the Old World until after the discovery of the New. It has probably been very long in cultivation. The others all belong to the Old World. Wheat and barley have been cultivated from the earliest times; according to De Candolle, the chief authority in these matters, about four thousand years. Later came rye and oats, both of which have been known in cultivation for at least two thousand years. Even the shorter of these periods gives time enough for wide variation, and as is to be expected there are numerous varieties of them all. For instance, Vilmorin, in 1880, figured sixty-six varieties of wheat with plainly distinguishable characters.[5]

If the Chinese records are to be trusted, rice has been cultivated for a period much longer than that assigned by our history and traditions to the other cereals, and the varieties are correspondingly numerous. It is said that in Japan above three hundred varieties are grown on irrigated lands, and more than one hundred on uplands.[6]

With the possible exception of rice, not one of the species of cereals is certainly known in the wild state.[7] Now and then specimens have been gathered in the East which can be referred to the

probable types from which our varieties have sprung, but doubt has been thrown upon every one of these cases. It has been shown conclusively that it is easy for a plant to escape from cultivation and persist in its new home even for a long time in a near approximation to cultivated form. Hence, we are forced to receive all statements regarding the wild forms with caution. But it may be safely said that if all the varieties of cereals which we now cultivate were to be swept out of existence, we could hardly know where to turn for wild species with which to begin again. We could not know with certainty.

To bring this fact a little more vividly to our minds, let us suppose a case. Let us imagine that a blight without parallel has brought to extinction all the forms of wheat, rice, rye, oats, barley and maize, now in cultivation, but without affecting the other grasses or any other form of vegetable food. Mankind would be obliged to subsist upon the other kindly fruits of the earth; upon root-crops, tubers, leguminous seeds, and so on. Some of the substitutions might be amusing in any other time than that of a threatened famine. Others would be far from appetizing under any condition, and only a few would be wholly satisfying even to the most pronounced vegetarian. In short, it would seem, from the first, that the cereals fill a place occupied by no other plants. The composition of the grains is theoretically and practically almost perfect as regards food ratio between the nitrogenous matters and the starch group; and the food value, as it is termed, is high. But aside from these considerations, it would be seen that for safety of preservation through considerable periods, and for convenience of transportation, the cereals take highest rank. Pressure would come from every side to compel us to find equivalents for the lost grains. From this predicament I believe that the well-equipped experiment stations and the agricultural departments in Europe and America would by and by extricate us. Continuing this hypothetical case, let us next inquire how the stations would probably go to work in the up-hill task of making partially good a well-nigh irreparable loss.

The whole group of relatives of the lost cereals would be passed in strict review. Size of grain, strength and vigor and plasticity of stock, adaptability to different surroundings, and flexibility in variation would be examined with scrupulous care.

But the range of experiment would, under the circumstances,

extend far beyond the relatives of our present cereals. It would embrace an examination of the other grasses which are even now cultivated for their grains, but which are so little known outside of their own limit, that it is a surprise to hear about them. For example, the millets, great and small, would be investigated. These grains, so little known here, form an important crop in certain parts of the east. One of the leading authorities on the subject[8] states that the millets constitute "a more important crop" in India "than either Rice or Wheat, and are grown more extensively, being raised from Madras in the south to Rajputana in the north. They occupy about eighty-three per cent of the food-grain area in Bombay and Sinde, forty-one per cent in the Punjab, thirty-nine per cent in the Central Provinces," "in all about thirty million acres."

Having chosen proper subjects for experimenting, the cultivators would make use of certain well-known principles. By simple selection of the more desirable seeds, strains would be secured to suit definite wants, and these strains would be kept as races, or attempts would be made to intensify wished-for characters. By skilful hybridizing of the first, second and higher orders, tendencies to wider variation would be obtained and the process of selection considerably expedited.[9]

It is out of our power to predict how much time would elapse before satisfactory substitutes for our cereals could be found. In the improvement of the grains of grasses other than those which have been very long under cultivation, experiments have been few, scattered and indecisive. Therefore we are as badly off for time-ratios as are the geologists and archæologists in their statements of elapsed periods. It is impossible for us to ignore the fact that there appear to be occasions in the life of a species when it seems to be peculiarly susceptible to the influences of its surroundings.[10] A species, like a carefully laden ship, represents a balancing of forces within and without. Disturbance may come through variation from within, as from a shifting of the cargo, or, in some cases from without. We may suppose both forces to be active in producing variation, a change in the internal condition rendering the plant more susceptible to any change in its surroundings. Under the influence of any marked disturbance, a state of unstable equilibrium may be brought about, at which times the species as such is easily acted upon by very slight agencies.

One of the most marked of these derangements is a consequent of cross-breeding within the extreme limits of varieties. The resultant forms in such cases can persist only by close breeding or propagation from buds or the equivalents of buds. Disturbances like these arise unexpectedly in the ordinary course of nature, giving us sports of various kinds. These critical periods, however, are not unwelcome, since skilful cultivators can take advantage of them. In this very field much has been accomplished. An attentive study of the sagacious work done by Thomas Andrew Knight shows to what extent this can be done.[11] But we must confess that it would be absolutely impossible to predict with certainty how long or how short would be the time before new cereals or acceptable equivalents for them would be provided. Upheld by the confidence which I have in the intelligence, ingenuity, and energy of our experiment stations, I may say that the time would not probably exceed that of two generations of our race, or half a century.

In now laying aside our hypothetical illustration, I venture to ask why it is that our experiment stations and other institutions dealing with plants and their improvement, do not undertake investigations like those which I have sketched. Why are not some of the grasses other than our present cereals studied with reference to their adoption as food grains? One of these species will naturally suggest itself to you all, namely, the Wild Rice of the Lakes.[12] Observations have shown that, were it not for the difficulty of harvesting these grains which fall too easily when they are ripe, they might be utilized. But attentive search might find or educe some variety of *Zizania*, with a more persistent grain and a better yield. There are two of our sea-shore grasses which have excellent grains, but are of small yield. Why are not these, or better ones which might be suggested by observation, taken in hand?

The reason is plain. We are all content to move along in lines of least resistance, and are disinclined to make a fresh start. It is merely leaving well enough alone, and so far as the cereals are concerned it is indeed well enough. The generous grains of modern varieties of wheat and barley compared with the well preserved charred vestiges found in Greece by Schliemann,[13] and in the lake-dwellings,[14] are satisfactory in every respect. Improvements, however, are making in many directions; and in the cereals we now

have, we possess far better and more satisfactory material for further improvement both in quality and as regards range of distribution than we could reasonably hope to have from other grasses.

From the cereals we may turn to the interesting groups of plants comprised under the general term

II. VEGETABLES.

Under this term it will be convenient for us to include all plants which are employed for culinary purposes, or for table use such as salads and relishes.

The potato and sweet potato, the pumpkin and squash, the red or capsicum peppers, and the tomato, are of American origin.

All the others are, most probably, natives of the Old World. Only one plant coming in this class has been derived from Southern Australasia, namely, New Zealand Spinach (*Tetragonia*).

Among the vegetables and salad-plants longest in cultivation we may enumerate the following—turnip, onion, cabbage, purslane, the large bean (Faba), chick-pea, lentil and one species of pea, garden pea. To these an antiquity of at least four thousand years is ascribed.

Next to these, in point of age, come the radish, carrot, beet, garlic, garden-cress, and celery, lettuce, asparagus and the leek. Three or four leguminous seeds are to be placed in the same category, as are also the black peppers.

Of more recent introduction the most prominent are, the parsnip, oyster plant, parsley, artichoke, endive and spinach.

From these lists I have purposely omitted a few which belong exclusively to the tropics, such as certain yams.

The number of varieties of these vegetables is astounding. It is, of course, impossible to discriminate between closely allied varieties which have been introduced by gardeners and seedsmen under different names, but which are essentially identical, and we must therefore have recourse to a conservative authority, Vilmorin,[15] from whose work a few examples have been selected. The varieties which he accepts are sufficiently well distinguished to admit of description and in most instances of delineation, without any danger of confusion. The potato has, he says, innumerable varieties, of which he accepts forty as easily distinguishable and worthy of a place in a general list, but he adds also a list, comprising, of course, synonyms, of thirty-two French, twenty-six English, nineteen American and eighteen German varieties. The following

numbers speak for themselves, all being selected in the same careful manner as those of the potato: celery more than twenty; carrot more than thirty; beet, radish and potato more than forty; lettuce and onion more than fifty; turnip more than seventy; cabbage, kidney bean and garden pea each more than one hundred.

The amount of horticultural work which these numbers represent is enormous. Each variety established as a race (that is a variety which comes true to seed) has been evolved by the same sort of patient care and waiting which we have seen is necessary in the case of cereals, but the time of waiting has not been as a general thing so long.

You will permit me to quote from Vilmorin[16] also an account of a common plant, which will show how wide is the range of variation and how obscure are the indications in the wild plant of its available possibilities. The example shows how completely hidden are the potential variations useful to mankind.

"Cabbage, a plant which is indigenous in Europe and Western Asia, is one of the vegetables which has been cultivated from the earliest time. The ancients were well acquainted with it, and certainly possessed several varieties of the head-forming kinds. The great antiquity of its culture may be inferred from the immense number of varieties which are now in existence, and from the very important modifications which have been produced in the characteristics in the original or parent plant.

The wild Cabbage, such as it now exists on the coasts of England and France, is a perennial plant, with broad-lobed, undulated, thick, smooth leaves, covered with a glaucous bloom. The stem attains a height of from nearly two and a half to over three feet, and bears at the top a spike of yellow or sometimes white flowers. All the cultivated varieties present the same peculiarities in their inflorescence, but up to the time of flowering they exhibit most marked differences from each other and from the original wild plant. In most of the Cabbages, it is chiefly the leaves that are developed by cultivation; these for the most part become imbricated or overlap one another closely, so as to form a more or less compact head, the heart or interior of which is composed of the central undeveloped shoot and the younger leaves next it. The shape of the head is spherical, sometimes flattened, sometimes conical. All the varieties which form heads in this way are known by the general name of Cabbages, while other kinds with large branching leaves which never form heads are distinguished by the name of Borecole or Kale.

In some kinds, the flower-stems have been so modified by culture as to become transformed into a thick, fleshy tender mass, the growth and enlargement of which are produced at the expense of the flowers which are absorbed and rendered abortive. Such are the Broccolis and Cauliflowers."

But this plant has other transformations.

"In other kinds, the leaves retain their ordinary dimensions, while the stem or principal root has been brought by cultivation to assume the shape of a large ball or turnip, as in the case of the plants known as Kohl-Rabi and Turnip-rooted Cabbage or Swedish Turnip. And lastly, there are varieties in which cultivation and selection have produced modifications in the ribs of the leaves, as in the Couve Tronchuda, or in the axillary shoots (as in Brussels sprouts), or in several organs together, as in the Marrow Kales, and the Neapolitan Curled Kale."

Here are important morphological changes like those to which Professor Bailey has called attention in the case of the tomato.

Suppose we are strolling along the beach at some of the seaside resorts of France, and should fall in with this coarse cruciferous plant, with its sprawling leaves and strong odor. Would there be anything in its appearance to lead us to search for its hidden merit as a food plant? What could we see in it which would give it a preference over a score of other plants at our feet? Again, suppose we are journeying in the high lands of Peru, and should meet with a strong-smelling plant of the Night-shade family, bearing a small irregular fruit, of sub-acid taste and of peculiar flavor. We will further imagine that the peculiar taste strikes our fancy, and we conceive that the plant has possibilities as a source of food. We should be led by our knowledge of the potato, probably a native of the same region, to think that this allied plant might be safely transferred to a northern climate, but would there be promise of enough future usefulness in such a case as this, to warrant our carrying the plant North as an article of food? Suppose, further, we should ascertain that the fruit in question was relished not only by the natives of its home, but that it had found favor among the tribes of South Mexico and Central America, and had been cultivated by them until it had attained a large size; should we be strengthened in our venture? Let us go one step farther still. Suppose that having decided upon the introduction of the plant, and having urged everybody to try it, we should find it discarded as a fruit, but taking a place in gardens as a curiosity under an absurd name, or as a basis for preserves and pickles; should we not look upon our experience in the introduction of this new plant as a failure? This is not an hypothetical case.

The Tomato,[17] the plant in question, was cultivated in Europe as long ago as 1554;[18] it was known in Virginia in 1781 and in the Northern States in 1785; but it found its way into favor slowly, even in this land of its origin. A credible witness states that in

Salem it was almost impossible to induce people to eat or even taste of the fruit. And yet, as you are well aware, its present cultivation on an enormous scale in Europe and this country is scarcely sufficient to meet the increasing demand.

A plant which belongs to the family of the tomato has been known to the public under the name of the strawberry tomato. The juicy yellow or orange-colored fruit is enclosed in a papery calyx of large size. The descriptions which were published when the plant was placed on the market were attractive, and were not exaggerated to a misleading extent. But, as you all know, the plant never gained any popularity. If we look at these two cases carefully we shall see that what appears to be caprice on the part of the public is at bottom common sense. The cases illustrate as well as any which are at command, the difficulties which surround the whole subject of the introduction of new foods.

Before asking specifically in what direction we shall look for new vegetables I must be pardoned for calling attention, in passing, to a very few of the many which are already in limited use in Europe and this country, but which merit a wider employment. Cardon, or Cardoon; Celeriac, or turnip-rooted celery; Fetticus, or corn-salad; Martynia; Salsify; Sea-kale; and numerous small salads, are examples of neglected treasures of the vegetable garden.

The following which are even less known may be mentioned as fairly promising.[19]

(1) *Arracacia esculenta*, called Arracacha, belonging to the Parsley family. It is extensively cultivated in some of the northern states of South America. The stems are swollen near the base, and produce tuberous enlargements filled with an excellent starch. Although the plant is of comparatively easy cultivation, efforts to introduce it into Europe have not been successful, but it is said to have found favor in both the Indies, and may prove useful in our Southern States.

(2) *Ullucus* or Ollucus, another tuberous rooted plant from nearly the same region, but belonging to the beet or spinach family. It has produced tubers of good size in England, but they are too waxy in consistence to dispute the place of the better tubers of the potato. The plant is worth investigating for our hot dry lands.

(3) A tuber-bearing relative of our common Hedge-nettle, or

Stachys, is now cultivated on a large scale at Crosnes in France, for the Paris market. Its name in Paris is taken from the locality where it is now grown for use. Although its native country is Japan, it is called by some seedsmen Chinese Artichoke. At the present stage of cultivation, the tubers are small and are rather hard to keep, but it is thought "that both of these defects can be overcome or evaded."[21] Experiments indicate that we have in this species a valuable addition to our vegetables. We must next look at certain other neglected possibilities.

Dr. Edward Palmer,[20] whose energy as a collector and acuteness as an observer are known to you all, has brought together very interesting facts relative to the food-plants of our North American aborigines. Among the plants described by him there are a few which merit careful investigation. Against all of them, however, there lie the objections mentioned before, namely:

(1) The long time required for their improvement, and

(2) The difficulty of making them acceptable to the community, involving

(3) The risk of total and mortifying failure.

In the notes to this address the more prominent of these are enumerated.

In 1854 the late Professor Gray called attention to the remarkable relations which exist between the plants of Japan and those of our eastern coast. You will remember that he not only proved that the plants of the two regions had a common origin, but also emphasized the fact that many species of the two countries are almost identical. It is to that country which has yielded us so many useful and beautiful plants that we turn for new vegetables to supplement our present food-resources. One of these plants, namely, *Stachys*, has already been mentioned as rather promising. There are others which are worth examination and perhaps acquisition.

One of the most convenient places for a preliminary examination of the vegetables of Japan is at the railroad stations on the longer lines, for instance, that running from Tokio to Kobe. For native consumption there are prepared luncheon boxes of two or three stories, provided with the simple and yet embarrassing chop-sticks. It is worth the shock it causes one's nerves to invest in these boxes and try the vegetable contents. The bits of fish, flesh and fowl which one finds therein can be easily separated and discarded, upon which there will remain a few delicacies. The pervading

odor of the box is that of aromatic vinegar. The generous portion of boiled rice is of excellent quality with every grain well softened and distinct, and this without anything else would suffice for a tolerable meal. In the boxes which have fallen under my observation there were sundry boiled roots, shoots and seeds which were not recognizable by me in their cooked form. Professor Georgeson,[22] formerly of Japan, has kindly identified some of these for me, but he says "there are doubtless many others used occasionally."

One may find sliced lotus roots, roots of large burdock, lily bulbs, shoots of ginger, pickled green plums, beans of many sorts, boiled chestnuts, nuts of the gingko tree, pickled greens of various kinds, dried cucumbers, and several kinds of seaweeds. Some of the leaves and roots are cooked in much the same manner as beet-roots and beet-leaves are by us, and the general effect is not unappetizing. The boiled shoots are suggestive of only the tougher ends of asparagus. On the whole, I do not look back on Japanese railway luncheons with any longing which would compel me to advocate the indiscriminate introduction of the constituent vegetables here.

But when the same vegetables are served in native inns, under more favorable culinary conditions, without the flavor of vinegar and of the pine wood of the luncheon boxes, they appear to be worthy of a trial in our horticulture, and I therefore deal with one or two in greater detail.

Professor Georgeson, whose advantages for acquiring a knowledge of the useful plants of Japan have been unusually good, has placed me under great obligations by communicating certain facts regarding some of the more promising plants of Japan which are not now used here. It should be said that several of these plants have already attracted the notice of the Agricultural Department in this country.

The soy bean (*Glycine hispida*). This species is known here to some extent, but we do not have the early and best varieties. These beans replace meat in the diet of the common people.

Mucuna (*Mucuna capitata*) and Dolichos (*Dolichos cultratus*) are pole beans possessing merit.

Dioscorea. There are several varieties with palatable roots. Years ago one of these was spoken of by the late Dr. Gray, as possessing "excellent roots, if one could only dig them."

Colocasia antiquorum has tuberous roots, which are nutritious.

Conophallus Konjak has a large bulbous root, which is sliced, dried and beaten to a powder. It is an ingredient in cakes.

Aralia cordata is cultivated for the shoots, and used as we use asparagus.

Œnanthe stolonifera and *Cryptotœnia Canadensis* are palatable salad plants, the former being used also as greens.

There is little hope, if any, that we shall obtain from the hotter climates for our southern territory new species of merit. The native markets in the tropical cities, like Colombo, Batavia, Singapore and Saigon, are rich in fruits, but outside of the native plants bearing these, nearly all the plants appear to be wholly in established lines of cultivation, such, for instance, as members of the gourd and night-shade families.

Before we leave the subject of our coming vegetables, it will be well to note a naive caution enjoined by Vilmorin in his work, Les Plantes Potagères.[23]

"Finally," he says, "we conclude the article devoted to each plant with a few remarks on the uses to which it may be applied and on the parts of the plants which are to be so used. In many cases such remarks may be looked upon as idle words, and yet it would sometimes have been useful to have them when new plants were cultivated by us for the first time. For instance, the giant edible burdock of Japan (*Lappa edulis*) was for a long time served upon our tables only as a wretchedly poor Spinach, because people would cook the leaves, whereas, in its native country, it is only cultivated for its tender fleshy roots."

I trust you are not discouraged at this outlook for our coming vegetables.

Two groups of improvable food-plants may be referred to before we pass to the next class, namely, edible fungi and the beverage plants. All botanists who have given attention to the matter agree with the late Dr. Curtis of North Carolina that we have in the unutilized mushrooms an immense amount of available nutriment of a delicious quality. It is not improbable that other fungi than our common "edible mushroom" will by and by be subjected to careful selection.

The principal beverage-plants, tea, coffee and chocolate, are all attracting the assiduous attention of cultivators. The first of these plants is extending its range at a marvellous rate of rapidity

through India and Ceylon; the second is threatened by the pests which have almost exterminated it in Ceylon, but a new species, with crosses therefrom, is promising to resist them successfully; the third, chocolate, is every year passing into lands farther from its original home. To these have been added the kola, of a value as yet not wholly determined, and others are to augment the short list.

III. FRUITS.

Botanically speaking, the cereal grains of which we have spoken are true fruits, that is to say, are ripened ovaries, but for all practical purposes they may be regarded as seeds. The fruits, of which mention is now to be made, are those commonly spoken of in our markets, as fruits.

First of all, attention must be called to the extraordinary changes in the commercial relations of fruits by two direct causes:

(1) The canning industry, and

(2) Swift transportation by steamers and railroads.

The effects of these two agencies are too well known to require more than this passing mention. By them the fruits of the best fruit-growing countries are carried to distant lands in quantities which surprise all who see the statistics for the first time. The ratio of increase is very startling. Take for instance, the figures given by Mr. Morris at the time of the great Colonial and Indian Exhibition, in London. Compare double decades of years.

1845, £886,888.
1865, £3,185,984.
1885, £7,587,523.

In the Colonial Exhibition at London, in 1886, fruits from the remote colonies were exhibited under conditions which proved that, before long, it may be possible to place such delicacies as the Cherimoyer, the Sweet-cup, Sweet-sop, Rambutan, Mango and Mangosteen, at even our most northern seaports. Furthermore, it seems to me likely that with an increase in our knowledge with regard to the microbes which produce decay, we may be able to protect the delicate fruits from injury for any reasonable period. Methods which will supplement refrigeration are sure to come in the very near future, so that even in a country so vast as our own, the most perishable fruits will be transported through its length and breadth without harm.

The canning industry and swift transportation are likely to diminish zeal in searching for new fruits, since, as we have seen in the case of the cereals, we are prone to move in lines of least resistance and leave well enough alone.

To what extent are our present fruits likely to be improved? Even those who have watched the improvement in the quality of some of our fruits, like oranges, can hardly realize how great has been the improvement within historic times in the character of certain pears, apples, and so on.

The term historic is used advisedly, for there are pre-historic fruits which might serve as a point of departure in the consideration of the question. In the ruins of the lake-dwellings in Switzerland,[24] charred apples have been found, which are in some cases, plainly of small size, hardly equalling ordinary crab apples. But, as Dr. Sturtevant has shown, in certain directions, there has been no marked change of type; the change is in quality.

In comparing the earlier descriptions of fruits with modern accounts it is well to remember that the high standards by which fruits are now judged are of recent establishment. Fruits which would once have been esteemed excellent, would to-day be passed by as unworthy of regard.

It seems probable that the list of seedless fruits will be materially lengthened, provided our experimental horticulturists make use of the material at their command. The common fruits which have very few or no seeds are the banana, pineapple and certain oranges. Others mentioned by Mr. Darwin as well known are the bread-fruit, pomegranate, azarole or Neapolitan medlar, and date palms. In commenting upon these fruits, Mr. Darwin[25] says that most horticulturists "look at the great size and anomalous development of the fruit as the cause and sterility as the result," but he holds the opposite view as more probable, that is, that the sterility, coming about gradually, leaves free for other growth the abundant supply of building material which the forming seed would otherwise have. He admits, however, that "there is an antagonism between the two forms of reproduction, by seeds and by buds when either is carried to an extreme degree which is independent of any incipient sterility."

Most plant-hybrids are relatively infertile, but by no means wholly sterile. With this sterility there is generally augmented vegetative vigor, as shown by Nägeli. Partial or complete ster-

ility and corresponding luxuriance of root, stem, leaves and flower, may come about in other obscure ways, and such cases are familiar to botanists.[10] Now it seems highly probable that either by hybridizing directed to this special end, or by careful selection of forms indicating this tendency to the correlated changes, we may succeed in obtaining important additions to our seedless or nearly seedless plants. Whether the ultimate profit would be large enough to pay for the time and labor involved is a question which we need not enter into; there appears to me no reasonable doubt that such efforts would be successful. There is no reason in the nature of things why we should not have strawberries without the so-called seeds; blackberries and raspberries, with only delicious pulp; and large grapes as free from seeds as the small ones which we call "currants" but which are really grapes from Corinth.

These and the coreless apples and pears of the future, the stoneless cherries and plums, like the common fruits before mentioned must be propagated by bud division, and be open to the tendency to diminished strength said to be the consequence of continued bud-propagation. But this bridge need not be crossed until we come to it. Bananas have been perpetuated in this way for many centuries, and pineapples since the discovery of America, so that the borrowed trouble alluded to is not threatening. First we must catch our seedless fruits.

Which of our wild fruits are promising subjects for selection and cultivation?

Mr. Crozier of Michigan has pointed out[26] the direction in which this research may prove most profitable. He enumerates many of our small fruits and nuts which can be improved.

Another of our most careful and successful horticulturists believes that the common blueberry and its allies are very suitable for this purpose and offer good material for experimenting. The sugar-plum, or so-called shadbush, has been improved in many particulars, and others can be added to this list.

But again we turn very naturally to Japan, the country from which our gardens have received many treasures. Referring once more to Professor Georgeson's studies,[27] we must mention the varieties of Japanese apples, pears, peaches, plums, cherries and persimmons. The persimmons are already well-known in some parts of our country, under the name of "kaki" and they will doubtless make rapid progress in popular favor.

The following are less familiar: *Actinidia arguta* and *volubilis*, with delicious berries;

Stauntonia, an evergreen vine, yielding a palatable fruit;

Myrica rubra, a small tree with an acidulous juicy fruit;

Elœagnus umbellata, with berries for preserves.

The active and discriminating horticultural journals in America and Europe are alive to the possibilities of new Japanese fruits, and it cannot be very long before our list is considerably increased.

It is absolutely necessary to recollect that in most cases variations are slight. Dr. Masters and Mr. Darwin have called attention to this and have adduced many illustrations, all of which show the necessity of extreme patience and caution. The general student curious in such matters can have hardly any task more instructive than the detection of the variations in such common plants as the blueberry, the wild cherry, or the like. It is an excellent preparation for a practical study of the variations in our wild fruits suitable for selection.

It was held by the late Dr. Gray that the variations in nature by which species have been evolved were led along useful lines, a view which Mr. Darwin regretted he could not entertain. However this may be, all acknowledge that by the hand of the cultivator, variations can be led along useful lines; and furthermore the hand which selects must uphold them in their unequal strife. In other words it is one thing to select a variety and another to assist it in maintaining its hold upon existence. Without the constant help of the cultivator who selects the useful variety, there comes a reversion to the ordinary specific type which is fitted to cope with its surroundings.

I think you can agree with me that the prospect for new fruits and for improvements in our established favorites is fairly good.

IV. TIMBERS AND CABINET WOODS.

Can we look for new timbers and cabinet woods? Comparatively few of those in common use are of recent introduction. Attempts have been made to bring into great prominence some of the excellent trees of India and Australia which furnish wood of much beauty and timber of the best quality. A large proportion of all the timbers of the South Seas are characterized by remarkable firmness of texture and high specific gravity.[28] The same is noticed in many of the woods of the Indies. A few of the heavier

and denser sorts, like Jarrah of West Australia, and Sabicu of the Caribbean Islands, have met with deserved favor in England, but the cost of transportation militates against them. It is a fair question whether, in certain parts of our country, these trees and others which can be utilized for veneers, may not be cultivated to advantage. Attention should be again called to the fact that many plants succeed far better in localities which are remote from their origin but where they find conditions substantially like those which they have left. This fact, to which we must again refer in detail with regard to certain other classes of plants, may have some bearing upon the introduction of new timber trees. Certain drawbacks exist with regard to the timber of some of the more rapidly growing hard-wood trees which have prevented their taking a high place in the scale of values in mechanical engineering.

One of the most useful soft-wooded trees in the world is the Kauri. It is restricted in its range to a comparatively small area in the North Island of New Zealand. It is now being cut down with a recklessness which is as prodigal and shameful as that which has marked our own treatment of forests here. It should be said, however, that this destruction is under protest, in spite of which it would seem to be a question of only a few years when the great Kauri groves of New Zealand will be a thing of the past. Our energetic Forest Department has on its hands problems just like this which perplexes one of the new lands of the South. The task in both cases is double: to preserve the old treasures and to bring in new.

The energy shown by Baron von Mueller, the renowned government botanist of Victoria, and by various forest departments in encouraging the cultivation of timber trees will assuredly meet with success; one can hardly hope that this success will appear fully demonstrated in the lifetime of those now living, but I cannot think that many years will pass before the promoters of such enterprises may take fresh courage.

In a modest structure in the city of Sydney, New South Wales, Mr. Maiden[28] has brought together, under great difficulties, a large collection of the useful products of the vegetable kingdom as represented in Australia. It is impossible to look at the collection of woods in that Museum or at the similar and more showy one in Kew, without believing that the field of forest culture must receive rich material from the southern hemisphere.

Before leaving this part of our subject, it may be well to take some illustrations in passing, to show how important is the influence exerted upon the utilization of vegetable products by causes which may, at first, strike one as being rather remote.

(1) Photography makes use of the effect of light on chromatized gelatin to produce under a negative the basis of relief plates for engraving. The degree of excellence reached in modifications of this simple device has distinctly threatened the very existence of wood engraving, and hence follows a diminished degree of interest in box-wood and its substitutes.

(2) Iron, and in its turn steel, is used in ship-building and this renders of greatly diminished interest all questions which concern the choice of the different oaks and similar woods.

(3) But, on the other hand, there is increased activity in certain directions, best illustrated by the extraordinary development of the chemical methods for manufacturing wood pulp. By the improved processes, strong fibers suitable for fine felting on the screen and fit for the best grades of certain lines of paper are given to us from rather inferior sorts of wood. He would be a rash prophet who should venture to predict what will be the future of this wonderful industry, but it is plain that the time is not far distant when acres now worthless may be covered by trees under cultivation growing for the pulp-maker.

There is no department of Economic Botany more promising in immediate results than that of Arboriculture.

V. VEGETABLE FIBERS.

The vegetable fibers known to commerce are either plant hairs, of which we take cotton as the type, or filaments of bast-tissue, represented by flax. No new plant hairs have been suggested which can compete in any way for spinning with those yielded by the species of Gossypium, or cotton, but experiments more or less systematic and thorough are being carried on with regard to the improvement of the varieties of the species. Plant hairs for the stuffing of cushions and pillows need not be referred to in connection with this subject.

Countless sorts of plants have been suggested as sources of good bast-fibers for spinning and for cordage, and many of these make capital substitutes for those already in the factories. But the questions of cheapness of production, and of subsequent prep-

aration for use, have thus far militated against success. There may be much difference between the profits promised by a laboratory experiment and those resulting from the same process conducted on a commercial scale. The existence of such differences has been the rock on which many enterprises seeking to introduce new fibers have been wrecked.

In dismissing this portion of our subject it may be said that a process for separating fine fibers from undesirable structural elements and from resin-like substances which accompany them, is a great desideratum. If this were supplied, many new species would assume great prominence at once.

VI. TANNING MATERIALS.

What new tanning materials can be confidently sought for? In his "Useful Native Plants of Australia," Mr. Maiden[28] describes over thirty species of "Wattles" or Acacias, and about half as many Eucalypts, which have been examined for the amount of tanning material contained in the bark. In all, eighty-seven Australian species have been under examination. Besides this, much has been done looking in the same direction at the suggestion and under the direction of Baron von Mueller, of Victoria. This serves to indicate how great is the interest in this subject, and how wide is the field in our own country for the introduction of new tanning plants.

It seems highly probable, however, that artificial tanning substances will at no distant day replace the crude matters now employed.

VII. RESINS, ETC.

Resins, oils, gums and medicines from the vegetable kingdom would next engage our attention if they did not seem rather too technical for this occasion, and to possess an interest on the whole somewhat too limited. But an allied substance may serve to represent this class of products and indicate the drift of present research.

India Rubber.[19]—Under this term are included numerous substances which possess a physical and chemical resemblance to each other. An Indian Ficus, the early source of supply, soon became inadequate to furnish the quantity used in the arts even when the manipulation of rubber was almost unknown. Later, supplies came from *Hevea* of Brazil, generally known as Para rubber,

and from *Castilloa*, sometimes called Central American rubber, and from *Manihot Glaziovii*, Ceara rubber. Not only are these plants now successfully cultivated in experimental gardens in the tropics, but many other rubber-yielding species have been added to the list. The Landolphias are among the most promising of the whole: these are the African rubbers. Now in addition to these which are the chief source of supply, we have *Willughbeia*, from the Malayan peninsula, *Leuconotis*, *Chilocarpus*, *Alstonia*, *Forsteronia*, and a species of a genus formerly known as *Urostigma*, but now united with *Ficus*. These names, which have little significance as they are here pronounced in passing, are given now merely to impress upon our minds the fact that the sources of a single commercial article may be exceedingly diverse. Under these circumstances search is being made not only for the best varieties of these species but for new species as well.

There are few excursions in the Tropics which possess greater interest to a botanist who cares for the industrial aspects of plants than the walks through the gardens at Buitenzorg in Java and at Singapore. At both these stations the experimental gardens lie at some distance from the great gardens which the tourist is expected to visit, but the exertion well repays him for all discomfort. Under the almost vertical rays of the sun, are here gathered the rubber-yielding plants from different countries, all growing under conditions favorable for decisions as to their relative value. At Buitenzorg a well-equipped laboratory stands ready to answer practical questions as to quality and composition of their products, and year by year the search extends.

I mention this not as an isolated example of what is being accomplished in Commercial Botany, but as a fair illustration of the thoroughness with which the problems are being attacked. It should be further stated that at the garden in question assiduous students of the subject are eagerly welcomed and provided with all needed appliances for carrying on technical, chemical and pharmaceutical investigations. Therefore I am justified in saying that there is every reason for believing that in the very near future new sources of our most important products will be opened up, and new areas placed under successful cultivation.

At this point, attention must be called to a very modest and convenient handbook on the Commercial Botany of the Nineteenth Century by Mr. Jackson of the Botanical Museum attached to the

Royal Gardens, Kew, which not only embodies a great amount of well-arranged information relative to the new useful plants, but is at the same time, a record of the existing state of things in all these departments of activity.

VIII. FRAGRANT PLANTS.

Another illustration of our subject might be drawn from a class of plants which repays close study from a biological point of view, namely, those which yield perfumes.

In speaking of the future of our fragrant plants we must distinguish between those of commercial value and those of purely horticultural interest. The former will be less and less cultivated in proportion as synthetic chemistry by its manufacture of perfumes replaces the natural by the artificial products; for example, Coumarin, Vanillin, Nerolin, Heliotropin, and even oil of wintergreen.

But do not understand me as intimating that chemistry can ever furnish substitutes for living fragrant plants. Our gardens will always be sweetened by them, and the possibilities in this direction will continue to extend both by contributions from abroad and by improvement in our present cultivated varieties. Among the foreign acquisitions are the fragrant species of *Andropogon*. Who would suspect that the tropical relatives of our sand-loving grasses are of high commercial value as sources of perfumery oils?

The utility to the plant of fragrance in the flower and the relation of this to cross-fertilization, are apparent to even a casual observer. But the fragrance of an aromatic leaf does not always give us the reason for its being.

It has been suggested for certain cases that the volatile oils escaping from the plants in question may, by absorption, exert a direct influence in mitigating the fierceness of action of the sun's rays. Other explanations have also been made, some of which are even more fanciful than the last.

When, however, one has seen that the aromatic plants of Australia are almost free from the attacks of insects and fungi, and has learned to look on the impregnating substances in some cases as protective against predatory insects and small foes of all kinds, and in others as fungicidal, he is tempted to ask whether all the substances of marked odor which we find in certain groups of plants may not play a similar rôle.

It is a fact of great interest to the surgeon that in many plants

there is associated with the fragrant principle a marked antiseptic or fungicidal quality; conspicuous examples of this are afforded by species of *Eucalyptus*, yielding Eucalyptol, *Styrax*, yielding Styrone, *Thymus*, yielding Thymol. It is interesting to note, too, that some of these most modern antiseptics were important constituents in the balsamic vulneraries of the earliest surgery.

IX. FLORISTS' PLANTS.

Florists' plants and the floral fashions of the future constitute an engaging subject which we can touch only lightly. It is reasonably clear that while the old favorite species will hold their ground in the guise of improved varieties, the new introductions will come in the shape of plants with flowering branches which retain their blossoms for a somewhat long period, and especially those in which the flowers precede the leaves. In short the next real fashion in our gardens is probably to be the flowering shrub and flowering tree, like those which are such favorites in the country from which the western world has gladly taken the gift of the chrysanthemum.[29]

Twice each year of late, a reception has been held by the Emperor and Empress of Japan. The receptions are in the autumn and in the spring. That in the autumn, popularly known as the Emperor's reception, has for its floral decorations the myriad forms of the national flower, the chrysanthemum; that which is given in spring, the Empress' reception, comes when the cherry blossoms are at their best. One has little idea of the wealth of beauty in masses of flowering shrubs and trees, until he has seen the floral displays in the Imperial Gardens and the temple grounds in Tokio.

To Japan and China also, we are indebted for many of the choicest plants of our gardens, but the supply of species is by no means exhausted. By far the larger number of desirable plants have already found their way into the hands of cultivators, but often under conditions which have restricted their dissemination through the flower-loving community. There are many which ought to be widely known, especially the fascinating dwarf shrubs and dwarf trees of the far east, which are sure to find sooner or later a warm welcome among us.

X. FORAGE PLANTS.

Next to the food-plants for man, there is no single class of com-

mercial plants of greater interest than the food-plants for flocks and herds. Forage plants, wild and cultivated, are among the most important and highly valued resources of vast areas. No single question is of more vital consequence to our farthest west and southwest.

It so happens that the plants on which the pastoralist relies grow or are grown on soil of inferior value to the agriculturist. Even soil which is almost sterile may possess vegetation on which flocks and herds may graze, and, further, these animals may thrive in districts where the vegetation appears at first sight too scanty or too forbidding, even to support life. There are immense districts in parts of the Australian continent where flocks are kept on plants so dry and desert-like that an inexperienced person would pass them by as not fit for his sheep, and yet, as Mr. Samuel Dixon[30] has well shown, these plants are of high nutritive value and are attractive to flocks.

Relegating to the notes to be published with this address brief descriptions of a few of the fodder plants suggested for use in dry districts, I shall now mention the salt-bushes of various sorts, and the allied desert plants of Australia as worth a careful trial on some of our very dry regions in the farthest west. There are numerous other excellent fodder plants adapted to dry but not parched areas which can be brought in from the corresponding districts of the southern hemisphere and from the East.

At an earlier stage of this address, I have had occasion to refer to Baron von Mueller, whose efforts looking towards the introduction of useful plants into Australasia have been aided largely by his convenient treatise on economic plants.[0] It may be said in connection with the fodder plants, especially, that much which the Baron has written can be applied *mutatis mutandis* to parts of our country.

The important subject of introducing fodder plants has been purposely reserved to the last because it permits us to examine a practical point of great interest. This is the caution which it is thought necessary to exercise when a species is transferred by our own choice from one country to another. I say, by our choice, for whether we wish it or not certain plants will introduce themselves. In these days of frequent and intimate intercommunication between different countries, the exclusion of foreign plants is simply impossible. Our common weeds are striking illustrations of the readiness with which plants of one country make for them-

selves a home in another.[31] All but two of the prominent weeds of the eastern states are foreign intruders.

There are all grades of persistence in these immigrants. Near the ballast grounds of every harbor, or the fields close by woollen and paper mills where foreign stock is used, you will observe many foreign plants which have been introduced by seed. For many of these you will search in vain a second year. A few others persist for a year or two longer, but with uncertain tenure of the land which they have invaded; others still have come to stay. But happily some of the intruders, which seem at first to gain a firm foothold, lose their ground after a while. We have a conspicuous example of this in a hawkweed, which was very threatening in New England two years ago, but is now relaxing its hold.

Another illustration is afforded by a water-plant which we have given to the old world. This plant, called in our botanies *Anacharis* or *Elodea*, is, so far as I am aware, not troublesome in our ponds and water-ways, but when it was carried to England, perhaps as a plant for the aquarium, it was thrown into streams and rivers with a free hand. It spread with remarkable rapidity and became such an unmitigated nuisance that it was called a curse. Efforts to extirpate it merely increased its rate of growth. Its days of mischief are however nearly over, or seem to be drawing to a close, at least so Mr. Lynch of the Botanic Gardens in Cambridge, England, and others of my informants think. The history of the plant shows that even under conditions which, so far as we can see, are identical with those under which the plant grew in its home, it may for a time take a fresh lease of life and thrive with an undreamed-of energy.

What did *Anacharis* find in the waters of England and the continent that it did not have at home, and why should its energy begin to wane now?

In Australasia one of the most striking of these intruders is sweet-briar. Introduced as a hedge plant it has run over certain lands like a weed, and disputes every acre of some arable plats. From the facility with which it is propagated, it is almost ineradicable. There is something astounding in the manner in which it gains and holds its ground. Gorse and brambles and thistles are troublesome in some localities, and they prove much less easy to control than in Europe. The effect produced on the mind of the colonist by these intruding pests is everywhere the same. When-

ever in an examination of the plants likely to be worthy of trial in our American dry lands, the subject was mentioned by me to Australians, I was always enjoined to be cautious as to what plants I might suggest for introduction from their country into our own. My good friends insisted that it was bad enough to have as pests the plants which come in without our planning or choice, and this caution seems to me one which should not be forgotten.

It would take us too far from our path to inquire what can be the possible reasons for such increase of vigor and fertility in plants which are transferred to a new home. We should have to examine all the suggestions which have been made, such as fresh soil, new skies, more efficient animal friends, or less destructive enemies. We should be obliged also to see whether the possible wearing out of the energy of some of these plants after a time, might not be attributable to the decadence of vigor through uninterrupted bud-propagation, and we should have to allude to many other questions allied to these. But, for this, time fails.

Lack of time also renders it impossible to deal with the questions which attach themselves to our main question, especially as to the limits of effect which cultivation may produce. We cannot touch the problem of inheritance of acquired peculiarities, or the manner in which cultivation predisposes the plant to innumerable modifications. Two of these modifications may be mentioned in passing, because they serve to exemplify the practical character of our subject.

Cultivation brings about in plants very curious morphological changes. For example, in the case of a well-known vegetable the number of metamorphosed type-leaves forming the ovary is two, and yet under cultivation, the number increases irregularly until the full number of units in the type of flower is reached. Professor Bailey of Cornell has called attention to some further interesting changes in the tomato, but the one mentioned suffices to illustrate the direction of variation which plants under cultivation are apt to take. Monstrosities are very apt to occur in cultivated plants, and under certain conditions may be perpetuated in succeeding generations, thus widening the field from which utilizable plants may be taken.

Another case of change produced by cultivation is likewise as yet wholly unexplained, although much studied; namely, the mutual interaction of scion and stock in grafting, budding, and the like.

It is probable that a further investigation of this subject may yet throw light on new possibilities in plants.

We have now arrived at the most practical question of all, namely:—

In what way can the range of commercial botany be extended?

In what manner or by what means can the introduction of new species be hastened?

It is possible that some of you are aware of the great amount of uncoördinated work which has been done and is now in hand in the direction of bringing in new plants.

The competition between the importers of new plants is so great both in the Old World and the New that a very large proportion of the species which would naturally commend themselves for the use of florists, for the adornment of greenhouses, or for commercial ends, have been at one time or another brought before the public or are being accumulated in stock. The same is true although to a less extent with regard to useful vegetables and fruit. Hardly one of those which we can suggest as desirable for trial has not already been investigated in Europe or this country, and reported on. The pages of our chemical, pharmaceutical, medical, horticultural, agricultural and trade journals, especially those of high grade, contain a wealth of material of this character.

But what is needed is this, that the promising plants should be systematically investigated under exhaustive conditions. It is not enough that an enthusiast here, or an amateur there, should give a plant a trial under imperfectly understood conditions, and then report success or failure. The work should be thorough and every question answered categorically, so that we might be placed in possession of all the facts relative to the object experimented upon. But such an undertaking requires the coöperation of many different agencies. I shall venture to mention some of these.

In the first place,—Botanic Gardens amply endowed for research. The Arnold Arboretum, the Shaw Garden, and the Washington Experimental Garden, are American illustrations of what is needed for this purpose. University gardens have their place in instruction, but cannot wisely undertake this kind of work.

In the second place,—Museums and Laboratories of Economic Botany. Much good work in this direction has been done in this country by the National Museum and by the department in charge[33] of the investigation of new plants. We need institutions like those

at Kew in England, and at Buitenzorg in Java, which keep in close touch with all the world. The founding of an establishment on a scale of magnitude commensurate with the greatness and needs of our country is an undertaking which waits for some one of our wealthy men.

In the third place,— Experiment Stations. These may, within the proper limits of their sphere of action, extend the study of plants beyond the established varieties to the species, and beyond the species to equivalent species in other genera. It is a matter of regret that so much of the energy displayed in these stations in this country, and we may say abroad, has not been more economically directed.

Great economy of energy must result from the recent change by which coördination of action is assured. The influence which the stations must exert on the welfare of our country, and the development of its resources is incalculable.

In the last place, but by no means least, the coöperation of all who are interested in scientific matters, through their observation of isolated and associated phenomena connected with plants of supposed utility, and by the cultivation of such plants by private individuals, unconnected with any state, governmental, or academic institutions.

By these agencies, wisely directed and energetically employed, the domains of commercial and industrial botany will be enlarged. To some of the possible results in these domains, I have endeavored to call your attention.

NOTES.

[0] The following are among the more useful works of a general character, dealing with the subject. Others are referred to either in the text or notes. The reader may consult also the list of works on Economic Botany in the catalogue published by the Linnæan Society.

Select Extra-tropical Plants, readily eligible for industrial culture or naturalization, with indications of their native countries and some of their uses. By BARON FERD. VON MUELLER, K.C.M.G., F.R.S., etc., Government Botanist for Victoria. (Melbourne), 1888. Seventh edition, revised and enlarged.

At the close of his treatise on industrial plants, Baron von Mueller has grouped the genera indicating the different classes of useful products in such a manner that we can ascertain the respective numbers belonging to the genera. Of course many of these genera figure in more than one category.

He has also arranged the plants according to the countries *naturally producing them.*

Useful Native Plants of Australia (including Tasmania). By J. H. MAIDEN, F.L.S., Curator of the Technological Museum of New South Wales, Sydney. (Sydney), 1889.

See also note 19.

Handbook of Commercial Geography. By GEO. G. CHISHOLM, M.A., B.Sc. London, 1889.

New Commercial Plants with directions how to grow them to the best advantage. By THOMAS CHRISTY (London), Christy and Co.

Dictionary of popular names of the plants which furnish the natural and acquired wants of man. By JOHN SMITH, A.L.S. (London), 1882.

Cultivated Plants. Their propagation and improvement. By F. W. BURBAGE. (London), 1877.

The Wanderings of Plants and animals from their first home. By VICTOR HEHN, edited by James Steven Stallybrass. (London), 1885.

Researches into the Early History of Mankind, and the Development of Civilization. By EDWARD B. TYLOR, D.C.L., LL.D., F.R.S., 1878.

[1] The number of species of Phænogamia has been given by many writers as not far from 150,000. But the total number of species recognized by Bentham and Hooker in the Genera Plantarum (Durand's Index), is 100,220, in 210 Natural Orders and 8,417 genera.

[2] Dr. E. Lewis Sturtevant, to whose kindness I am indebted for great assistance in the matter of references has placed at my disposal many of his notes on edible plants, etc. From his enumeration it appears that if we count all the plants which have been cultivated for food at one time or another, the list contains 1,192 species; but if we count all the plants which "either habitually or during famine periods are recorded to have been eaten," we obtain a list of no less than 4,690 species, or about three and one-half per cent of all known species of plants. But, as Sir Joseph Hooker has said, the products of many plants, though eatable, are not fit to eat.

[3] The Folk-Lore of Plants. By T. F. Thiselton Dyer, 1889.

[4] In Dr. Sturtevant's list, 88 species of Gramineæ are counted as food-plants under cultivation, while the number of species in this order which can be or have been utilized as food amounts to 146. Our smaller number 20 comprises only those which have been grown on a large scale anywhere.

[5] "In Agricultural Museum at Poppelsdorf, 600 varieties are exhibited."

[6] E. L. S. in letter. Quoted from Seedman's catalogue.

[7] The best account of the early history of these and other cultivated plants can be found in the classical work of De Candolle "*Origine des Plantes Cultivées* (Paris) translated in the International series, *History of Cultivated Plants* (N. Y.). The reader should consult also DARWIN'S *Animals and Plants under Domestication.*

[8] *Food-grains of India,* A. H. CHURCH, London, 1886, p. 34. In this instructive work the reader will find much information regarding the less common articles of food. Of *Panicum frumentaceum,* Professor Georgeson states in a letter that it is grown in Japan for its grain which is used for food, but here would take rank as a fodder plant.

[9] In order to avoid possible misapprehension, it should be stated that there are a few persons who hold that at least some of our cereals, and other cultivated plants, for that matter, have not undergone material improvement but are essentially unmodified progeny. Under this view, if we could look back into the farthest past, we should see our cereals growing wild and in such admirable condition that we should unhesitatingly select them for immediate use. This extreme position is untenable.

Again, there are a few extremists who hold that some plants under cultivation have reached their culminating point, and must now remain stationary or begin to retrograde.

[10] *Gray's Botanical Text-Book.* Vols. i and ii.

[11] *A Selection from the Physiological and Horticultural Papers,* published in the Transactions of the Royal and Horticultural Societies, by the late THOMAS ANDREW KNIGHT, Esq., President of the Hort. Soc. London (London), 1841.

[12] *Illustrations of the Manners, Customs and Conditions of the North American Indians.* By GEORGE CATLIN, London, 1876. A reprint of the account published in 1841 of travels in 1832-40.

"Plate 278 is a party of Sioux, in bark canoes (purchased of the Chippewas), gathering the wild rice, which grows in immense fields around the shores of the rivers and lakes of these northern regions, and used by the Indians as an article of food. The mode of gathering it is curious and, as seen in the drawing, one woman paddles the canoe, whilst another with a stick in each hand, bends the rice over the canoe with one, and strikes it with the other, which shakes it into the canoe, which is constantly moving along until it is filled." Vol. ii, p. 208.

[13] Schliemann's carbonized specimens exhumed in Greece are said to be "very hard, fine-grained, sharp, very flat on grooved side, different from any wheats now known." Am. Antiq., 1880, 66.

The carbonized grains in the Peabody Museum at Cambridge, Mass., are small.

[14] *Prehistoric Times* as illustrated by Ancient Remains and the manners and customs of modern savages. By JOHN LUBBOCK, Bart. (New York), 4th ed., 1886.

"Three varieties of wheat were cultivated by the Lake Dwellers, who also possessed two kinds of barley and two of millet. Of these the most ancient and most important were the six-rowed barley and small 'Lake Dwellers" wheat. The discovery of Egyptian wheat (*Triticum turgidum*), at Wangen and Robenhausen, is particularly interesting. Oats were cultivated during the bronze age, but are absent from all the stone age villages. Rye was also unknown," p. 216.

"Wheat is most common, having been discovered at Merlen, Moosseedorf and Wangen. At the latter place, indeed, many bushels of it were found, the grains being in large thick lumps. In other cases, the grains are free, and without chaff, resembling our present wheat in size and form, while more rarely they are still in the ear." 115 species of plants have been identified. Heer Keller.

[15] *Les Plantes Potagères*, VILMORIN, Paris. Translated into English under the direction of W. Robinson, editor of the (London) "Garden," 1885, and entitled *The Vegetable Garden*.

[16] *l. c.*, English Ed., p. 104.

[17] According to notes made by Mr. Manning, Sec. Massachusetts Horticultural Society (Hist. Mass. Hort. Society), the tomato was introduced into Salem, Mass., about 1802 by Michele Felice Corné, an Italian painter, but he found it difficult to persuade people even to taste the fruit (Felt's Annals of Salem, vol. ii, 631). It was said to have been introduced into Philadelphia by a French refugee from San Domingo in 1798. It was used as an article of food in New Orleans in 1812, but was not sold in the markets of Philadelphia until 1829. It did not come into general use in the north until some years after the last named date.

[18] "In Spain and those hot regions, they use to eat the (Love) apples prepared and boiled with pepper, salt and olives; but they yield very little nourishment to the bodies, and the same nought and corrupt. Likewise they doe eat the apples with oile, vinegar, and pepper mixed together for sauce to their meat even as we in these Cold Countries do Mustard." GERARD'S *Herbal*, 346.

[19] *Commercial Botany of the Nineteenth Century.* By JOHN R. JACKSON, A. L. S. Cassell and Company, London, 1890.

Mr. Jackson who is the Curator of the Museum, Royal Gardens, Kew, has embodied in this treatise a great amount of valuable information, well arranged for ready reference.

[20] *Department of Agriculture Report* for 1870, p. 404–428. Only those are here copied from Dr. Palmer's list which he expressly states are extensively used.

Ground-nut (*Apios tuberosa*); *Æsculus Californica*; *Agave Americana*; *Nuphar advena*; Prairie potato (*Psoralea esculenta*); *Scirpus lacustris*; *Sagittaria variabilis*; Kamass-root (*Camassia esculenta*); *Solanum Fendleri* (supposed by him to be the original of the cultivated potato; Acorns

of various sort; Mesquite (*Algarobia glandulosa*); *Juniperus occidentalis;* Nuts of *Carya*, *Juglans*, etc.; Screw-bean (*Strombocarpus pubescens*); various Cactaceæ; *Yucca;* Cherries and many wild berries; *Chenopodium album*, etc.

Psoralea esculenta=prairie potato, or Bread-root. Palmer in Agl. Report, 1870, p. 402.

The following from CATLIN, *l. c.*, i, p. 122:

"Corn and dried meat are generally laid in in the fall, in sufficient quantities to support them through the winter. These are the principal articles of food during that long and inclement season; and in addition to them, they oftentimes have in store great quantities of dried squashes, and dried pommes blanches,' a kind of turnip which grows in great abundance in those regions . . . . . These are dried in great quantities and pounded into a sort of meal and cooked with dried meat and corn. Great quantities are also dried and laid away in store for the winter season, such as buffalo berries, service berries, strawberries, and wild plums."

"In addition to this we had the luxury of service berries without stint; and the buffalo bushes, which are peculiar to these northern regions, lined the banks of the river and the defiles in the bluffs, sometimes for miles together, forming almost impassable hedges, so loaded with the weight of their fruit that their boughs everywhere gracefully bending down or resting on the ground. This last shrub (*Shepherdia*), which may be said to be the most beautiful ornament that decks out the wild prairies, forms a striking contrast to the rest of the foliage, from the blue appearance of its leaves by which it can be distinguished for miles in distance. The fruit which it produces in such incredible profusion, hanging in clusters to every limb and to every twig, is about the size of ordinary currants and not unlike them in color and even in flavor; being exceeding acid, almost unpalatable until they are bitten by frost of autumn, when they are sweetened and their flavor delicious, having to the taste much the character of grapes, and I am almost to think would produce excellent wine." GEORGE CATLIN'S *Illustrations of the Manners, Customs, and Conditions of the North American Indians*, p. 72, vol. i.

For much relative to the food of our aborigines, especially of the western coast, consult The Native Races of the Pacific States of North America. By H. H. Bancroft (New York), 1875. The following from vol. i, p. 538, indicates that inaccuracies have crept into the work: "From the earliest information we have of these nations" (the author is speaking of the New Mexicans), "they are known to have been tillers of the soil; and though the implements used and their methods of cultivation were both simple and primitive, cotton, corn, *wheat*, beans, and many varieties of fruit which constituted their principal food were raised in abundance."

Wheat was not grown on the American continent until after the landing of the first explorers.

[21] Gard. Chron., 1888.

[22] Pickled Daikon, the large radish, often grated.

Ginger roots—Shoga.

Beans (*Glycine hispida*)—many kinds and prepared in many ways.

Beans (*Dolichos cultratus*)— cooked in rice and mixed with it.

Sliced Hasu— Lotos roots.

Lily bulbs— boiled whole and the scales torn off as they are eaten.

Pickled green plums (Ume-boshi)— colored red in the pickle, by the leaves of *Perilla arguta* (Shiso).

Sliced and dried cucumbers—Kiuri.

Pieces of Gobo—roots of *Lappa major*.

Rakkio—bulbs of *Allium Bakeri*, boiled in Shogu.

Grated Wasabi—stem of *Eutrema Wasabi*.

Water-cress—Midzu-tagarashi (not often).

Also sometimes pickled greens of various kinds, and occasionally chestnut-kernels boiled and mixed with a kind of sweet sauce.

Nut of the Ginkgo tree.

Several kinds of seaweeds are also very commonly served with the rice. Prof. C. C. Georgeson in letter.

[23] *l. c.* Preface in English Edition.

[24] "Carbonized apples have been found at Wangen, sometimes whole, sometimes cut in two, or, more rarely, into four pieces and evidently dried and put aside for winter use . . . . . They are small and generally resemble those which still grow wild in the Swiss forests; at Robenhausen, however, specimens have occurred which are of larger size, and probably cultivated. No trace of the vine, the walnut, the cherry or the damson has yet been met with, but stones of the wild plum and the *Prunus padus* have been found." LUBBOCK, *l. c.*, p. 217.

[25] *Animals and Plants under Domestication* (Am. Ed.), vol. ii, p. 205–209. See also an interesting list of Seedless fruits given by Dr. E. Lewis Sturtevant. Memoirs of Torrey Botanical Club, N. Y.

[26] *American Garden*, N. Y. 1800–91.

[27] *American Garden*, N. Y. 1891.

[28] *Useful Native Plants of Australia*, by J. H. MAIDEN, Sydney.

[29] *The Flowers of Japan* and the Art of Floral Arrangement. By JOSIAH CONDER, F.R.I.B.A., Architect to the Imperial Japanese Government. Yokohama, 1891. See also two other works by the same author: Theory of Japanese Flower-arrangements, and Art of Landscape-gardening in Japan. (1886).

[30] MR. SAMUEL DIXON'S list is in vol. iii (for 1884–85) of the *Transactions and Proceedings and Report of the Royal Society of South Australia*. Adelaide, G. Robertson, 1886.

Bursaria spinosa— "a good stand-by," after the grasses dry up.

Pomaderris racemosa— "stands stocking well."

Pittosporum phyllaeroides—"sheep exceedingly partial to its foliage."

Casuarina quadrivalvis— "tenderness of fibre of wool would be prevented by it in our finer wool districts."

Acacias, The Wattles— "value as an astringent, very great," being curative of a malady often caused by eating frozen grass.

Acacia aneura (mulga)— "must be very nutritious to all animals eating

it." This is the plant which is such a terror to the stockmen who have to ride through the "scrub."

Cassia—some of the species with good pods and leaves for sheep.

The foregoing are found in districts which are not wholly arid.

The following are, more properly, "dry" plants.

Sida petrophila—"as much liked by sheep as by marsupials."

Dodonœa viscosa—Native Hop-bush. "Likes warm, red, sandy ground."

Lycium australe—"drought never seems to affect it."

Kochia aphylla—"all kinds of stock are often largely dependent on it during protracted droughts."

Rhagodia parabolica—"produces a good deal of foliage."

Atriplex vesicaria—"can be readily grown wherever the climate is not too wet."

I have transferred only those which Mr. Dixon thinks most worthy of trial. Compare also Dr. VASEY'S valuable studies of the plants of our dry lands, especially Grasses and Forage plants (1878), Grasses of the arid districts of Kansas, Nebraska and Colorado (1886), Grasses of the South (1887).

[31] The weeds of German gardens and agricultural lands are mostly from Mediterranean regions, but the invasions in the uncultivated districts are chiefly from America (such as *Œnothera*, *Mimulus*, *Rudbeckia*). Handbuch der *Pflanzengeographie*, von Dr. OSCAR DRUDE (Stuttgart), 1890, p. 97.

[33] The list of economic plants published by the Department in Washington is remarkably full, and is in every way creditable to those in charge.

The First National Scientific Congress (Washington, April 1844) and its Connection with the Organization of the American Association. By Prof. G. Brown Goode, Director of the National Museum, Washington, D. C.

In telling the story of the American Association, it is generally said that it was a *direct* continuation of the old Association of American Geologists and Naturalists.[1] In a certain sense this is true. At its meeting in New York in 1847, the Association of Geologists and Naturalists voted to enlarge its scope, to change its name to "The American Association for the Promotion of Science," and elected an officer to preside at the meeting of the new society in the following year. In September, 1847, the new association held its first meeting, and Prof. William B. Rogers, the chairman of the last meeting of the *old* association, presided during the proceedings and, after the adoption of a constitution, introduced his successor Prof. William C. Redfield, president elect. Thus was the American Association born, on the 20th of September, 1848, in Philadelphia. Its subsequent history is accessible to all, and the thirty-nine stout volumes which contain the records of its annual proceedings are permanent monuments to the wisdom of the founders.

All the circumstances of its origin, the causes of its founding and the influences which shaped its development have not as yet been exhaustively studied, and it is not impossible that valuable suggestions may be derived from a consideration of the other societies which were organized in the United States during the first half of the century.

Most powerful and important of all of these was the National Institution for the Promotion of Science, established in Washington only three weeks after the Association of Geologists held its first session in Philadelphia—the two societies having been essentially contemporaneous in origin. Besides these two there were no others which at that time aspired to national influence. *The Ameri-*

[1]This was organized in 1840 under the name of the Association of American Geologists.

can Philosophical Society and *The American Academy of Arts and Sciences*, in earlier days more far-reaching, were already limited by local bonds. *The United States Military Philosophical Society*, organized in 1803, the first in America to hold meetings from city to city, had disbanded soon after 1810. *The American Geological Society*, organized in New Haven in 1819, endured only until 1826. Others, like *The Academy of Natural Sciences of Philadelphia* and the *New York Lyceum of Natural History*, while not strictly local, were essentially professional societies, with interests already intentionally restricted.

The American Association was undoubtedly a direct outgrowth of the Association of Geologists and Naturalists, but it was not strictly a continuation. The older society was an assemblage of professional men. They were all geologists, for in those days every naturalist was to some extent a geologist, and the already extensive system of state geological surveys offered many opportunities for research. There was not an astronomer, mathematician, physicist, anthropologist, or political economist among them. Their object was described in the constitution to be "the advancement of Geology and the collateral branches of science," and geology remained always the paramount and controlling interest. The few papers on biological, chemical and meteorological subjects which were presented were written with geological problems in mind, and in the discussions geological considerations always received the chief attention. This tendency was especially pronounced previous to 1844 when a change of policy began to take place. It is evident to whomsoever may study the records that the American Association of Geologists was the legitimate successor of the American Geological Society, more closely akin to it (though separated by a period of fourteen years of lifelessness), than to its administrative offspring, the American Association. The Geological Society of America, separated from it by a gap of over forty years, is also more closely akin to it than was its outgrowth the American Association.

The Association of Geologists was only one of the parents of the American Association. For the other we must look to the National Institution; and since the achievements of this organization have hitherto received but slight consideration it seems appropriate on this occasion to call attention to the principal facts in its history.

This Society was from its start extremely comprehensive in its scope — even more so, it may be, than the American Association for the Advancement of Science has been at any period in its existence. Although its meetings, like those of the already venerable sister societies of similar purpose the American Philosophical Society, and the American Academy of Arts and Sciences, were always held in one city, its scope was essentially national and at the time of its greatest prosperity it had nearly sixteen hundred names upon its membership roll.

Its most peculiar feature was the circumstance that its active supporters were men of high official rank in the national government, who attended its meetings, occupied the chair, and delivered addresses and communications. It is much to be regretted that this association of public men with scientific organizations has not been continued in the last half of the present century, in the same way that it was in the first seventy-five years of our national existence. The agency of John Adams in founding the American Academy, the labors of Franklin, Jefferson, Washington, Gallatin, Madison, John Quincy Adams, in connection with the American Philosophical Society, are well known to all. In the closing years of the last century, when the national seat of government was in Philadelphia, the meetings of the American Philosophical Society were attended and largely kept up by high officials of the government.

When Washington became the national capital attempts were made from time to time to supply the want of scientific organizations, and from 1808 when a meeting of the United States Military Philosophical Society—the first national scientific society with a peripatetic system of meetings—was held in Washington City, there appears to have been always a place of assemblage for men of scientific tastes at the National Capital, where cultivators of the sciences met together for conference and discussion.

Somewhere between 1810 and 1815, an organization known as The Metropolitan Society was in existence in Washington. This in 1816 became the Columbian Institute for the Promotion of Arts and Sciences, of which John Quincy Adams, Samuel L. Southard, Daniel Webster, Henry Clay, John C. Calhoun, Edward Everett, and many other public men were supporters, and whose meetings were held in a room in the Capitol. The Columbian Institute, dormant after 1825, in 1840 passed into the National Institution for the Promotion of Science.

The National Institution, in April, 1844, instituted in Washington the first national Congress of scientific men—the first cosmopolitan assemblage of the kind which in any respect foreshadowed the great congresses of the American Association in later years. This gathering was upon the occasion of the first annual or general meeting of the Institution, and to it were invited the members of the American Philosophical Society, as the oldest scientific institution in the country, the members or the American Association of Naturalists and Geologists, and the members of all other scientific and learned societies in the United States, and all others engaged and concerned in the increase and diffusion of knowledge among men.

It is not necessary to describe at length the proceedings upon this occasion. They may be found in the Bulletin of the Institution which, though rare, is usually possessed by all the older libraries. The opening address was delivered by John Tyler, President of the United States, and the introductory discourse by the Hon. Robert J. Walker, U. S. senator from Mississippi— a learned and judicious essay, which reviewed very carefully the achievements of American Science, and is well worthy of a reading even at the present time. Senator Woodbury of New Hampshire, the Ex-President John Quincy Adams, M. C. from Massachusetts, the Hon. J. R. Ingersoll of Pennsylvania, and the Hon. John C. Spencer, Secretary of War, occupied the chair from day to day, and forty-three papers were read. So important were these that it is a matter of regret that few of them appear to have been published. They were prepared by representative men, and related to every branch of scientific enquiry at that time enlisting attention.

They were distributed as follows:

GENERAL.

Prof. Alexander Dallas Bache, Supt. of the U. S. Coast Survey. On the Condition of Science in the United States and Europe.

Peter A. Browne, LL.D. of Philadelphia. On an Improved Method of Teaching the Natural Sciences.

Hon. Richard Rush. On the Smithsonian Bequest.

Prof. S. S. Haldeman. On the necessity of a National Institution for the encouragement of Science.

MATHEMATICS AND GEODESY.

Prof. C. Gill of New York. On the Improvement of the Mathematical Sciences and the Consequent Advancement of the Natural Sciences.

Capt. W. A. Swift, U. S. A. On the Measurement of Base Lines.

ASTRONOMY.

Prof. John William Draper of the University of New York. On the Physical Constitution of the Rays of the Sun.

Prof. Elias Loomis of Western Reserve College, Ohio. On the Great Comet of 1843.

Prof. Richard S. McCulloh of Baltimore. On the Attraction of a Planet upon a Material Point in Space.

Prof. William Augustus Norton of Delaware College, Newark, Del. On the Nebular Hypothesis.

Rev. Prof. James Curley of Georgetown College, Washington, D. C. Description of a Meridian Circle for the Observatory of Georgetown College, D. C.

PHYSICS.

Prof. Benjamin Hallowell of Maryland. On the Liberation of Caloric in some Chemical Changes that are attended with an enlargement of Bulk.

Capt. A. Mordecai, U. S. A. Notice of a Ballistic Pendulum, constructed at Washington Arsenal for Experiments in Gunnery.

John Tyler, jr., of Washington. In support of the Theory of Our Electric Fluid.

METEOROLOGY.

Prof. M. Jacobs of Pennsylvania. On the Indian Summer.

Prof. J. P. Espy of Washington. On Meteorology.

Prof. J. Hamilton of the University of Nashville. On certain Meteorological facts observed at Nashville.

Lieut. Matthew Fontaine Maury, U. S. N. On the Gulf Stream.

George Baker and I. Thurber of Providence. On the Tides of Providence River and Narragansett Bay.

Prof. Robert Hare of the University of Pennsylvania. A Call for Observations on the Lake Storm.

Prof. A. D. Bache, LL.D. An Abstract of Magnetical and Meteorological Observations made under the direction of the War Department, at the Observatory Girard College, Philadelphia.

GEOLOGY.

Prof. William Williams Mather of Ohio University. On the Physical Geology of the United States.

Rev. Eliphalet Nott, D.D., LL.D., President of Union College. On the Origin, Duration and End of the World.

Prof. J. H. Agnew of New York. On the Glacier System or Ice Period of Agassiz.

Prof. John Locke of the Medical College of Ohio, Cincinnati. On Lake Superior, embracing an account of Miscellaneous Observations on the Geology, Mineralogy, Topography, Scenery, Climate, Meteorology, etc., etc., of the Lake.

PALEONTOLOGY.

WILLIAM B. HODGSON of Savannah, Ga. On the Megatherioid Fossils of the Atlantic coast of Georgia.

A. D. CHALONER, M.D., of Philadelphia. A Petrified Forest near Cairo, Egypt.

ZOOLOGY.

REV. JOHN G. MORRIS, D.D., of Baltimore. On the Past and Present State of Entomology in the United States.

PROF. J. W. BAILEY, U. S. Military Academy. Notes on American Polythalamia.

PHYSIOLOGY, PHARMACOLOGY.

DR. W. H. VAN BUREN, U. S. A. On the Effects of Large Doses of Sulphate of Quinine on the Human System, as a Remedial Agent.

PROF. J. R. W. DUNBAR of Maryland. On the Importance of Physiology as a branch of General Education.

ANTHROPOLOGY, PHILOLOGY.

J. C. PICKETT, U. S. chargé d'affaires, Cima. Remarkable Ruins in the Provinces of Chachapoyas, Peru.

GEORGE E. CHASE, U. S. A., of Pensacola, Fla. A method of settling the orthography and orthoepy of the English Language.

ADMINISTRATIONS, INSTITUTIONS, STATISTICS, ETC.

REV. HECTOR HUMPHREYS, D.D., President of St. John's College, Annapolis, Md. On the Economy of Science as Relating to the Government.

PROF. EDWARD FORMAN of Baltimore. On Domestic Exchanges in Natural History and Geology.

PROF. THOMAS SEWALL, M.D., of Washington. On the Design of the Medical Department of the National Institute.

PROF. R. M. PATTERSON of Philadelphia. On a method of determining the centre of population of a country.

POLITICAL ECONOMY, HISTORY, ETC.

PROF. GEORGE TUCKER of the University of Virginia. On the Dangers most to be guarded against in the Future Progress of the United States.

F. J. GRUND of Philadelphia. On the Modern Historical Schools of France and Germany and the Philosophy of History.

PROF. WALTER R. JOHNSON of Philadelphia. On the Scientific Character and Researches of the late James Smithson.

HON. A. H. EVERETT of Massachusetts. On the Moral Tendency of the Science and Learning of the Past and Present Centuries.

FRANCIS LIEBER, LL.D., of South Carolina. Remarks on Public Institutions.

At the meeting of the Association of American Geologists held in Washington in the following month out of thirty-one formal papers read, while twenty-five were mostly geological or paleontological, four related to zoology and two to chemistry or physics.

It was doubtless intended that the first annual meeting or Congress of the National Institution should be followed by a similar gathering each year. This was clearly indicated in Senator Walker's introductory address, in which the opinion is forcibly expressed that the National Institution, with its central location, could, better than any other society then in existence, bring together the varied state interests and form a body truly national in its influence. (Bulletin of the National Institution, p. 439.)

This Institute is located at the home of the Federal Government, and its operations are designed to embrace the whole Union. Rising above local and sectional influences, it appeals to the friends of science throughout the nation, and asks the support of all, with a view to the general diffusion of knowledge, and advancement of American science. It is not designed to impede the progress or impair the usefulness of any present or future scientific institutions or societies in any of the States, but would desire to establish between them and this Institute the most cordial relations, together with reciprocal aid and encouragement. Experience has proved that no one institution, however distinguished, of any State, can bring to its aid the combined efforts and support of the whole Union. Each State will desire the advancement of its own institutions; and here only can all meet beyond the limits of all the States, and unite, as Americans, in erecting and maintaining an institution which shall be truly national, not only in its location, but in all its operations. Whilst the hopes of this Institute are most elevated for the future, its present pretensions are truly humble. It does not claim to have established the character or assumed the position of a scientific institution; it does not pretend to teach the men of science of the nation, but seeks instruction from them, and appeals to them, for light and aid and encouragement. It asks them to come forward in a patriotic spirit, and make this Institute worthy of the great nation at the seat of whose Government it is placed, and where only the now scattered lights of American science can converge at a common centre, and radiate thence throughout the whole circle of the whole Union.

Disaster soon befell the National Institution. Many of its founders and supporters disappeared from public life. The Smithsonian fund, which it aspired to control, was placed under other authority. The collections and manuscripts of the exploring expeditions were removed from its custody. The magnificent collections in natural history, ethnology and geology, which had accu-

mulated as a result of its wonderful activity and enthusiasm, soon became a burden and a source of danger, for Congress refused the financial aid which its projectors had counted upon as certain, and which they doubtless would have received but for political changes not foreseen at the start. Only one annual meeting was held, and the publication of the bulletin containing its proceedings was its last creditable effort. It lingered along, and in 1861 went out of existence by the termination of its charter, having existed for twenty-one years, the last sixteen of which, inglorious as they were, could not impair the brilliancy of its early history.

Not only did it accomplish a great work in preparing the way for enlightened legislation regarding scientific matters in general, but it achieved definite and tangible results in connection with the founding of the Smithsonian Institution, the National Observatory, the National Museum, the reorganization of the Coast Survey and the publication of the reports of the exploring expeditions; and it had, as an attempt will now be made to show, a direct influence upon the origin of the American Association for the Advancement of Science.

Several of the most influential members of the Association of Geologists and Naturalists took part in the general meeting of the National Institution in 1844, Browne, Locke, Maury, Johnson, Morris, Bailey, Mather, Haldeman and Morton. Others, who joined the Association for the Advancement of Science in its earliest years, were also present, and saw for themselves the advantages and opportunities afforded by such gatherings.

The leaven began to work. In the meeting for 1844 there were four biological and two chemical papers. The Association of Geologists and Naturalists in 1845 announced that "a constant effort has been made to counteract the impression that the objects of the Association are exclusively geological or directed to those cognate subjects only which have a direct bearing upon that subject," and to throw open its doors widely for all cultivators of science and the arts who choose to enter. In 1847, at the eighth meeting, the papers belonged to all branches of science. Thirty-seven were read, of which nine related to geology, seven to paleontology, seven to zoology, five to chemistry and physics, three to anthropology, three to meteorology, one to institutions.[1]

[1] Amer. Jour. of Science, 2d Ser. IV, 1847, p. 428.

The new society was born, and it is significant that the name first adopted was as nearly as possible a combination of the names of the two parent organizations. The one contributed the first half of the name—"The American Association;" the other the second half—"for the promotion of science." The word advancement in place of promotion was substituted afterwards, probably by the first Committee on Rules. Even if it were possible, it would be scarcely worth while to determine the proportionate extent of the participation of either of the two societies in the early history of the American Association. The influence of the National Institution should, however, have due recognition, and the fact should not be forgotten that under its auspices, and in the city of Washington forty-seven years ago, took place the first national congress of American men of science.

It seems appropriate that the remaining seven years of the first half century of the American Association should be devoted by those concerned in the organization of American science to a unification and concentration of the forces, which now, not purposely, but actually are in part centrifugal. The midsummer meeting of the Association this year has brought around it a cluster of other meetings of kindred bodies. It is worth the effort to endeavor to induce the other societies of professional men of science to meet in conjunction with our great Association. To bring this about, it might be necessary to hold two meetings in the year—one in midsummer at some city of hotels at the seashore or in the mountains; another in the winter holidays, in some large city, where the Associations would be brought into relationship with local institutions at the time of greatest activity. A winter meeting would render it possible for all of the kindred societies of specialists and professional workers to meet in connection with the Association occasionally, or it may be each year. It would be a glorious occasion if, when the American Association in 1898 *enters upon the second half of its first century, it should have actually assumed its natural functions as the central agency for all American scientific effort.*

SECTION A.

MATHEMATICS AND ASTRONOMY.

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F. H. BIGELOW of Washington, D. C., in the absence of E. D. Preston.

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ADDRESS

BY

PROFESSOR E. W. HYDE.

VICE PRESIDENT, SECTION A.

THE EVOLUTION OF ALGEBRA.

In considering the possible subjects for an address on this occasion, it has seemed to me that a half hour might be agreeably spent in a brief survey of the progress, or evolution, of Algebra from its earliest known beginnings to the present time.

The realm of mathematics may be classified, in a general way, into

(1) Arithmetic, or the Theory of Numbers;

(2) Algebra;

(3) Geometry;

though sharp dividing lines cannot always be drawn between these departments; the last two, for instance, mutually interacting, geometry illustrating algebra, while algebra is the efficient servant of geometry, enabling it to conquer territory which it could scarcely have entered upon unaided.

The history of the development of these different branches of mathematics shows considerable diversities among them. Thus geometry reached in a short time, among the ancient Greeks, a high stage of advancement, and then became practically stationary until quite recent times, while the progress of algebra has been more in the nature of a gradual and continuous evolution. Nesselmann has recognized three stages in this development which he designates as the *Rhetorical*, the *Syncopated*, and the *Symbolical*, to which I may perhaps venture to add the *Multiple*, in which a plurality of fundamental units is recognized and treated. We may regard the first three as somewhat analogous to the Stone, Bronze and Iron ages in human history, overlapping each other, as do

these, at different times and places; while the last may be compared to that age of aluminum which is perhaps dawning upon the world.

Rhetorical algebra was a process for determining the unknown quantity in an equation by a course of logical reasoning expressed entirely in words, without the use of any symbols whatever, similar to our present mental arithmetic. In course of time abbreviations of those words which constantly occurred were introduced, by the use of which the statement of the reasoning could be much shortened, it being even possible with the notation of Diophantos to approximate to the conciseness of the modern, or symbolic, method. This, however, was not done by Diophantos himself, who used his abbreviations strictly as such, and reasoned out his results in words combined with these. This method is what is designated by Nesselmann as the Syncopated, and forms evidently a stepping stone toward the symbolic, in which perfectly arbitrary symbols are employed to represent the various quantities dealt with, and no words are written out except a conjunction now and then.

The earliest traces of algebraic knowledge which have been discovered are found in Egypt, that wonderful land whose records carry us back to such a remote antiquity. Ahmes, in a papyrus MS. dating from about 1400 or 1500 B. C., deals with certain geometric and algebraic problems, and seems to have had as good a conception of the symbolism of algebra as his successors of a much later period. Thus he had signs for $+$, $-$ and $=$, and used the character representing a *heap* for the unknown quantity. He seems therefore to have long anticipated Diophantos in the use of a syncopated notation. Our knowledge of Egyptian mathematics subsequent to this time is very slight, and is gleaned from the statements of various Greek and Latin authors.

We will pass then at once to the Greek contributions to the development of our subject. So far as can now be ascertained probably but little strictly algebraic work was done before the third or fourth century of our era, though opinions differ on this point. The wonderful accomplishments of Archimedes were mainly geometrical and mechanical, though he makes one remark which is equivalent to a statement regarding the roots of an equation of the third degree, which is remarkable as being, with one exception, the only known case of any consideration of such an equation until after the lapse of more than a thousand years from this time.

Thymaridas in the second century of our era is the earliest mathematician known to have enunciated an algebraic theorem. This was, however, done entirely in words, no symbol for any quantity or operation being used.

Practically the foundation of algebra was laid by Diophantos of Alexandria. But little is known of this remarkable man. Though we have his writings in Greek, he was probably not himself a Greek. The period at which he lived is in dispute, though probabilities favor the fourth century of our era. Even the spelling of his name is uncertain, there being a question as to whether the last syllable should be *os* or *es*. But whatever may be known or unknown about the man himself, his writings show a very wonderful power of analytic reasoning, especially when we consider the awkwardness of the tools with which he was obliged to work.

What strikes us at once, from our present point of view, as most hampering is the fact that he had only *one* symbol for the unknown; so that, in dealing with a problem which would now be solved by x, y, z, etc., he was obliged to adopt some expedient, such as to make *mentally* such combinations and arrangements as to get along with only one. It is easy to see how much ingenuity must often have been required to accomplish this. It is a curious and surprising fact that algebraic analysis was subjected to this same limitation down to a comparatively recent period. In place of the exponents at present used to indicate the powers to which quantities are raised, Diophantos designated the square and cube of the unknown by the initial letters of the corresponding words in Greek. Thus the unknown is represented by the character ς, standing for the word ἀριθμός (*i. e.* number), which is also frequently written out in full; the square of the same by δ^{υ}, a contraction for δύναμις (power) and the cube by κ^{υ}, a contraction for κύβος (cube). Higher powers up to the sixth were indicated by combination or repetition of these symbols. The origin of the character for arithmos is uncertain; it may be the final sigma of this word, or it may be a contraction of α ρ the first two letters of the same, or it may be derived from an old Egyptian symbol for the unknown. When oblique cases of these quantities are required the words for square and cube are written out in full, while the practice varies with regard to arithmos, the word being sometimes written out, while at other times the case termination is written above to the right, thus $\varsigma^{\hat{o}\upsilon}$, the symbol being also generally doubled when the signification is plural.

Diophantos indicated addition merely by *juxtaposition*, having no sign for plus; for minus however he used the sign $\wp$. As a consequence, in order to avoid confusion, he was obliged to do two things:

First, to designate the absolute term as so many μονάδες, or units, abbreviated into $\mu^{\hat{o}}$, and

Second, to write all the negative terms together after the positive. Thus the quantity $x^3 - 5x^2 + 8x - 1$ would be written in Diophantos' notation

$$x^{\hat{v}}\bar{\alpha}\varsigma\varsigma^{\hat{o}\hat{\imath}}\eta\wp\delta^{\hat{v}}\bar{\epsilon}\mu^{\hat{o}}\bar{\alpha}.$$

This may be rendered more expressive, if we change it by substituting Arabic numerals, and putting U for units, N for number or unknown, S for square and C for cube; thus it becomes

C 1 N 8 — S 5 U 1.

It is to be noted that Diophantos and his successors up to comparatively recent times had no conception whatever of an intrinsically negative quantity as possible. Whatever sign may have been used for minus was considered as simply indicating that one number was to be subtracted from another, and if the subtrahend were larger than the minuend no meaning was attached to the expression.

It is possible that Diophantos might have been able to escape from the limitations of his system if the letters of the Greek alphabet had not been already appropriated for the representation of *particular* numbers, thus precluding their use as symbols of quantity in general.

It may be of interest to give at this point specimens of the purely rhetorical, and of the syncopated methods of solution. They are given by Nesselmann, and are verbatim translations from the original tongues. The first is a solution of a quadratic equation by Mohammed ibn Musa, and the second the solution of a problem by Diophantos.

Rhetorical Method.

A *square* and ten of its *roots* are equal to nine and thirty *units*, that is, if you add ten *roots* to one *square*, the sum is equal to nine and thirty. The solution is as follows: halve the number of *roots*, that is, in this case five; then multiply this by itself, and the result is five and twenty. Add this to the nine and thirty, which gives four and sixty; take the square root, or eight, and subtract from it half the number of *roots*, namely five, and there remain three;

this is the *root* of the *square* which was required and the *square* itself is nine.

Syncopated Method.

(S = square, N = number, U = unit as above.)

To divide the proposed square into two squares. Let it be proposed then to divide 16 into two squares; and let the first be supposed to be one *square*. Thus 16 minus one *square* must be equal to a square. I form the square from any number of N's minus as many U's as there are in the side of 16 U's. Suppose this to be 2 N's minus 4 U's. Thus the square itself will be 4 *squares*, 16 U's minus 16 N's. These are equal to 16 *units* minus 1 *square*. Add to each the negative term and take equals from equals. Thus 5 *squares* are equal to 16 *numbers*, and the *number* is 16 fifths. One (square) will be 256 twenty-fifths and the other 144 twenty-fifths, and the sum of the two makes up 400 twenty-fifths, or 16 *units*, and each is a square.

Compare these long drawn out statements with their equivalents in modern notation.

1	2
$x^2 + 10x = 39$	$16 - x^2 = [\,] = (2x - 4)^2$
$x^2 + 10x + 25 = 64$	$= 4x^2 + 16 - 16x$
$x + 5 = 8$	$16\,x = 5x^2$
$x = 3$	$x = \frac{16}{5}$

The example from Diophantos evidently does not take full advantage of his notation, for the symbol for minus is not used, and in several cases the words are written out in full where abbreviations might have been employed. Further no use is made of the symbol for equality, viz., ι, an abbreviation for ἴσοι, which is elsewhere used by this author. If the fullest use of the syncopated notation had been made, the solution would have been somewhat comparable for conciseness and brevity with the modern method, only about twice as many characters and marks being required. Solutions in this abbreviated form appear on the margins of Diophantos' MS., but they are believed to have been added by some one else, and not to be due to the author himself.

The works of Diophantos, called by him "Arithmetics," deal largely with indeterminate equations and the theory of numbers. Quadratic equations are constantly solved, but only *real positive* results are recognized or considered; and even when there are *two*

positive roots only one is taken account of. One very simple case of an equation of the 3rd degree is found.

We will turn next to the consideration of the ancient algebra of India. There lived at Patna, in India, some time in the sixth century of our era, a mathematician named Arya-Bhatta, who wrote a work treating of arithmetic, algebra, geometry, trigonometry and astronomy. It consists in the enunciation of rules and propositions in verse. The author gives, of course in a purely rhetorical manner, the sums of the 1st, 2nd and 3rd powers of the first n natural numbers, the general solution of a quadratic equation, and the solution in integers of some indeterminate equations of the 1st degree.

The only other ancient Indian mathematician of prominence is *Brahmagupta* who lived in the seventh century of our era. His work is also written in verse, and is called *Brahma-Sphuta-Siddhanta*, or the "system of Brahma in astronomy." Two chapters of this work deal with arithmetic, algebra and geometry. The treatment of algebra is purely rhetorical, and includes a discussion of arithmetical progressions, quadratic equations (only the positive roots being considered), and indeterminate equations of the 1st degree, together with *one* of the 2nd degree.

These Indian writings are of special interest as being the sources from which the Arabs derived their first knowledge of algebra. They obtained from the Greeks, before 900 A. D., through translations of Euclid, Apollonius, Archimedes and others, a knowledge of geometry, mechanics and astronomy, but had no translation of Diophantos till one hundred and fifty years later, when they had themselves already made considerable progress in algebraic analysis. From the Arabians in turn western Europe obtained not only the decimal notation of arithmetic, but also its first knowledge of other branches of mathematics.

The first great mathematician among the Arabs is generally known by the name of Alkarismi, though this is an incorrect transliteration of only *one* of his names. From the title of his work, *Al-gebr we'l mukabala*, we have the *name* of that branch of mathematics under consideration, Al-gebr signifying that the same quantity may be added to or subtracted from both sides of an equation.

Alkarismi treats the quadratic, giving geometric proof of rules for the solution of different cases, and recognizing the *existence* of *two* roots, though he only considers such as are real and positive.

He treats only numerical equations, and no distinction is made between arithmetic and algebra. This is true likewise of his Arabian successors who, though they advanced so far as to obtain the general solution of a cubic equation, and to state such a proposition as that no solution in integers of the equation $x^3+y^3=z^3$ is possible, yet always adhered to the rhetorical method, and made scarcely any progress in general algebraic science. Indeed such progress was hardly possible until the introduction of symbolic methods.

The first decided steps in the direction of symbolism since the work of Diophantos were taken by a mathematician of India named Bhaskara in the twelfth century. He uses abbreviations and initials to denote the unknown, a dot for minus and juxtaposition to indicate addition. A product is denoted by the first syllable of the word for multiplication subjoined to the factors, division by the divisor being written beneath the dividend without a line between as our custom is now. The two sides of an equation are written one under the other, and explanatory words are introduced whenever it is necessary to prevent misunderstanding. Occasionally symbols are used for given as well as unknown quantities. Square, cube and square root are denoted by the initial letters of the corresponding words. Using the Arabic, or decimal, notation, he has a character for zero, which enables him to write all his equations with all the powers of the unknown arranged in regular order on each side of the equation, certain of them being multiplied by the factor zero. This method of writing equations maintained itself till long afterwards. We have in this author a distinct advance over Diophantos and the Arabians in the introduction of various symbols for the unknown so that several might be used in the same problem, as well as in the use of zero.

We have now to consider a new phase of algebraic progress arising from the introduction into western Europe of the works of the Arabian mathematicians. This took place through the Moors of Spain. The Greek and Arabic works were studied at the Moorish Universities of Granada, Cordova and Seville, but all knowledge of them was jealously kept from the outside world until the twelfth century, during which copies came into the possession of Christians. Up to this time Christian Europe had been almost a mathematical blank. The simple arithmetical operations they were able to perform were accomplished by the aid of the

abacus, and they possessed some knowledge of astronomy and geometry, but made no progress until they were able to avail themselves of the previous labors of Greek, Hindoo and Arab, under the stimulus of which a career of advancement began which has continued to the present time. This career, however, did not begin immediately; it took several centuries to assimilate the material received from these sources, and thus to lay the foundations on which subsequent progress should rest.

During this period the rhetorical method was used in all algebraic processes, and it was not until the sixteenth century that syncopated methods were introduced, preparing the way for the symbolic methods that soon followed. Latin being the language in use, the word *res* or *radix*, was employed for the unknown quantity, the square being called *census*, and the cube *cubus*. These words were at first written out in full and afterwards represented by R or Rj, Z or C and C or K respectively.

The signs $+$ and $-$ are first found in a mercantile arithmetic by Johann Widmann published in 1489, though they did not come into general use by mathematicians till one hundred years or more afterwards. The most probable supposition as to their origin is that they were at first warehouse marks indicating an excess or deficiency in the contents of a package which was supposed to contain a certain definite amount. Widmann uses them purely as abbreviations, not as symbols of operation.

The first mathematical work ever *printed* was by Pacioli upon arithmetic, algebra and geometry, and marks the beginning of the syncopated stage of development in western Europe. This book appeared in 1494, just before the beginning of the sixteenth century during which this method was in vogue. Pacioli uses initials as abbreviations for the unknown, its square and cube, and for the words plus and equal, also occasionally *de* for demptus instead of minus.

The sign now used for equality was introduced by Recorde in an arithmetic published in 1540. He uses also the present signs $+$ and $-$. At about the same time our present symbol for square root was introduced by Stifel, and Nicholas Tartaglia discovered the solution of the cubic equation $x^3 + px = q$ which is generally attributed to Cardan, and goes by his name. Cardan obtained the solution from Tartaglia under promise of strict secrecy and then published it in his work called *Ars Magna*. Considerable advance is made

in this work over anything done by his predecessors. Negative and even imaginary roots of equations are discussed, and the latter are shown to occur always in pairs, though no interpretation of them is attempted. Cardan shows that when the roots of the cubic are all real, Tartaglia's solution appears in an imaginary form. This is the first notice we find of imaginaries, and, with the exception of a similar treatment by Bombelli a few years later, and a suggestion as to their interpretation by Wallis in 1685, they were discussed by no subsequent mathematician until Euler investigated them nearly two hundred years afterward. Cardan also discovered the relations between the roots and coëfficients of an algebraic equation, and the underlying principle of Descartes' rule of signs. It is to be noted that his solutions both of quadratics and cubics are *geometrical*.

In 1572 Bombelli published an algebra in which the same subjects discussed by Cardan are treated in about the same way, but in which a marked advance is made in *notation*, viz.—the employment for the unknown of the symbol $\overset{1}{\smile}$, while its powers are denoted by $\overset{2}{\smile}$, $\overset{3}{\smile}$, etc. Thus he would write $x^2 + 5x - 4$ as $1\overset{2}{\smile}$ p. $5\overset{1}{\smile}$ m. 4, p. and m. standing for plus and minus. Other writers of the same period would have written the expression thus: 1Z p. 5R. m. 4, or 1 Q + 5N — 4.

Up to this time in the development of algebraic notation, whatever may have been the forms or symbols used, they were regarded simply as abbreviations for the words necessary to express the idea to be conveyed. But now the conception of pure symbolism begins to appear. Vieta, who lived in the last half of the sixteenth century, denoted known quantities by consonants and unknown by vowels, while powers were indicated by initials or abbreviations of the words quadratus and cubus. He was thus enabled to deal with several unknowns in the same problem, together with their powers. The following is a specimen of his notation: The equation $3\,BA^2 - DA + A^3 = Z$ he writes as *B 3 in A quad. — D plano in A + A cubo equatur Z solido.* (It may be noted that he makes his equations *homogeneous*, and lays stress on the desirability of so doing.) This and the other examples that have been given above illustrate the great variety of notations in use during this period, no conventional system having yet been adopted to be adhered to in the main by all mathematical writers. This is, of course, an inevitable accompaniment of the formative stage of any branch of science, when a few men are working here and there in comparative isolation.

This variety continued to a considerable extent throughout the seventeenth century.

In this century we arrive at a new era in mathematical development. This was brought about by the application of algebra to geometry by Descartes in the early part, and the discovery of the Differential Calculus by Newton and Leibnitz independently in the latter part of the century. Algebra had been used in connection with geometry before Descartes, but to him was due the discovery of the fact that, if the position of a point be given by coördinates, then any equation involving those coördinates will represent some locus all of whose properties are contained implicitly in the equation, and may be deduced therefrom by ordinary algebraic operations.

Descartes initiated the custom, which has become fixed, of using the first letters of the alphabet for known and the last for unknown quantities. He also appears to have been the first to perceive that one general proof is sufficient for any proposition algebraically treated, the different cases which might arise by different arrangements of the equations being covered by the possibility of any letter representing a negative as well as a positive quantity, *i. e.*, he distinguished the *intrinsic* sign of a quantity or symbol. Hitherto it had been considered necessary to treat separately the forms of the quadratic $ax^2 + bx = c$, $ax^2 = bx + c$, etc., which was a natural result of the geometric method of arriving at the solution. Descartes also introduced our present notation for powers, taking his exponents however only as positive and integral.

Contemporaneously with Descartes, Cavalieri, in Italy, applied the so-called "method of indivisibles" to the computation of areas, volumes, etc., a process which gave way early in the eighteenth century to the Integral Calculus. At this time also the beginnings of the mathematical theory of probabilities were made by Pascal and Fermat in the solution of a certain problem which had been proposed.

A tremendous impulse was given to all branches of mathematics in the latter part of the seventeenth century by the genius of Newton. Besides his epoch-making discovery of the "Theory of Fluxions" or Differential Calculus, he contributed to algebraic science the idea of the general exponent or n^{th} power, n being positive, negative, integral, or fractional, the binomial theorem, and a considerable part of the Theory of Equations.

To Leibnitz we owe the present notation of the Differential Cal-

culus, the introduction of the terms "coördinates" and "axes of coördinates," and suggestions as to the use of indeterminate coëfficients and determinants, which, though not developed by him, led, in the hands of others, to important results.

Jacob Bernoulli developed the fundamental principles of the calculus of probabilities, and made the first systematic attempts to construct an Integral Calculus. His brother John developed the exponential calculus, and treated trigonometry independently as a branch of analysis, it having been previously regarded as an adjunct of astronomy. The possibility of a calculus of *operations* was first recognized by Brook Taylor after whom Taylor's Theorem is named. DeMoivre contributed to the discussion of imaginaries the important theorem which bears his name. In 1748 Mac Laurin published an algebra which contained the results of some earlier papers published by him, among others one on the number of imaginary roots of an equation, and one on the determination of equal roots by means of the first derivative.

In the latter part of the eighteenth century and beginning of the nineteenth, mathematical advancement was rapid under the powerful hands of Euler, Lagrange, Laplace and Legendre. To these great men we owe the Calculus of Variations, the initial discussion of the Calculus of Imaginaries, which was afterwards systematized and developed by Gauss, Cauchy and others, the treatment of Determinants, contributions to the Theory of Equations, a large part of the Integral Calculus and Differential Equations, the development of the Theory of Probabilities, the treatment of Elliptic Functions, the method of Least Squares, and the specially algebraic treatment of the Theory of Numbers. In this list are included only those things which are of an algebraic nature.

We have now reached the beginning of our own century in which the advance has been so rapid in all directions as to preclude more than a mere indication of some of the lines along which this has taken place, without any attempt at an enumeration of the illustrious names of those who have so magnificently carried forward the work.

The theory of equations has been perfected by the full use of the complex unit $a+bi$, forming thus, in the words of Cayley, a "Universe complete in itself, such that starting in it we are never led out of it." We have in fact a *double* algebra as the instrument for the complete treatment of all higher analysis, except that in

which one of higher multiplicity is used. The field of Quantics has been brilliantly cultivated by Cayley, Sylvester and others. The theory of Matrices has been developed by Cayley, and it was shown by Prof. J. Willard Gibbs, in his Vice Presidential address before this Section at the Buffalo meeting in 1886, that the simple and natural expression of this theory is in the language of multiple algebra. The φ of Hamilton is a matrix of the 3rd order, and the Q of Grassmann a matrix of the n^{th} order.

In the treatment of differential equations we have an algebra of operations, due primarily to Geo. Boole, carried to a high degree of perfection, in which the symbol of differentiation is treated precisely as if it were a real quantity. In fact, we have come to regard scalar multiplication simply as a particular case in the Calculus of operations which covers every possible case of the effect of one symbol upon another in producing some change in it. A further extension of this same idea we have in the Algebra of Logic, invented by the same author and cultivated and extended by others since his time.

In conclusion, I propose to sketch briefly the development of the idea of a multiplicity of fundamental units, which is pervading more and more the mathematical thought of the day. This proceeded along two distinct lines, one arising from the interpretation of the imaginary $\sqrt{-1}$, and the other entirely independent of this symbol or operator.

The first attempt to give a geometric meaning to the expression $a+bi$ appears to be due to Wallis in 1685, who proposed to construct the imaginary roots of a quadratic by going out of the line on which they would have been laid off if real.

In 1804 the Abbé Buée devised the now accepted representation by laying off the terms containing i as a factor, at right angles to the others, and showed how to add and subtract such expressions as $a+bi$. At about the same time Argand published independently the same idea, and still further developed it. The concept of a *directed* quantity as represented by an algebraic symbol was thus necessarily arrived at. Gauss, Cauchy and others have elaborated the complex unit more especially in the theory of *numbers*, while Euler, Peacock, De Morgan and others have developed it more as a *double algebra*.

Up to this point i had been regarded as a *scalar* operator merely, and the corresponding geometry only *plane*, though attempts had

been made without much success to extend the treatment into three-dimensional space. It remained for Hamilton to accomplish this by the simple device of making i a *directed* operator, or handle, perpendicular to the plane of rotation, which opened the way for any number of similar operators differing in *direction*, but, as to their other properties, simply square roots of minus one. In order to produce a convenient algebra on this basis, Hamilton was obliged to take the further step of giving to *all* vectors the properties of $\sqrt{-1}$, and thus the Calculus of Quaternions was produced, a non-commutative, quadruple algebra. These ideas have been generalized still further by Unverzagt in his "Theorie der Goniometrischen und der Longimetrischen Quarternionen." In this book the author first developed a trigonometry based on a general instead of a right angled triangle, and then shows that the operator $j=(-1)^{\frac{\lambda}{\pi}}$ (in which λ is the fundamental angle, taking the place of $\frac{\pi}{2}$) takes in this trigonometry the place of i in De Moivre's Theorem generalized. He then takes three units, j_1, j_2, j_3, corresponding to Hamilton's i, j, k, and forms a generalized quaternion, based on some angle λ, which reduces to the ordinary system when $\lambda=\frac{\pi}{2}$. The case particularly discussed is that in which $\lambda=0$.

The theory and laws of *linear*, *associative algebras*, which includes quaternions as a particular case, have been thoroughly treated by Peirce in his work bearing that title.

We turn now to the other line along which multiple algebras have been developed.

In 1827 Möbius published his "Barycentrische Calcül," in which *points* are the ultimate units, to which any desired weights may be assigned. He gave the laws of combination of these units so far as addition and subtraction are concerned, but did not proceed to multiplication; in fact he distinctly states that they can be multiplied only by numbers. He then proceeds to treat analytical geometry on this basis. His treatment of points, so far as it goes, is on the same plan afterwards independently developed by Grassmann.

In 1844, one year after Hamilton's first announcement of his discovery, Grassmann published his *Ausdehnungslehre*, which contains a complete and logical exposition of his new algebra for any number of independent units, and hence, geometrically interpreted, for space of any dimensions. This work was so abstract and

general in form, and so unlike the ordinary language of mathematics, that it attracted hardly any notice, and the author was obliged to recast and republish it in 1862. Grassmann's Algebra is non-linear, and only partially associative, so that it differs fundamentally from all those discussed by Peirce. The $\sqrt{-1}$ plays no part whatever in the theory, and Grassmann's vector is a vector pure and simple, *i. e.*, a quantity having direction and magnitude, and not, as in quaternions, a *versor*-vector combining the properties of a vector and of the $\sqrt{-1}$. The fundamental notion of Grassmann's multiplication is *extension* or *generation;* the product $p_1 p_2$ is the line generated by a point moving straight from p_1 to p_2, etc.

In this great invention of Grassmann we have a multiple algebra which is the natural language of geometry and mechanics, dealing in a manner astonishingly simple, concise and expressive with these subjects, and certain, it appears to me, to gain constantly in the appreciation of mathematicians as it is more generally understood and used. The fact of its perfect adaptability to n-dimensional space is an additional argument in its favor for those who are interested in that line of investigation.

We have now traced the development of our subject from its elementary beginnings through a long period in which it was in the rhetorical stage, approaching at intervals here and there to the syncopated; then on the revival of learning in Europe after the dark ages, we have seen its comparatively rapid progress through the syncopated stage to the purely symbolical, when it was at last in a shape suitable for the astonishing progress of the last 200 years.

Finally, in the present century, we have noted the appearance, as in the fullness of time, of multiple algebras from different and independent sources, whose realm is that of the future.

PAPERS READ.

PRINCIPLES OF THE ALGEBRA OF PHYSICS. By Prof. A. MACFARLANE, University of Texas, Austin, Texas.

[This paper was read before a joint session of Sections A and B on August 21.]

La seule manière de bien traiter les élémens d'une science exacte et rigoureuse, c'est d'y mettre toute la rigueur et l'exactitude possible.

D'ALEMBERT.

The question as to the possibility of representing areas and solids by means of the apparent multiplication of the symbols for lines has always appeared to me to be one of great difficulty in the application of algebra to geometry; nor has the difficulty, I think, been properly met in works on the subject.

D. F. GREGORY.

Tant que l'algèbre et la géometrie ont été séparés, leur progrès ont été lents et leurs usages bornés, mais lorsque ces deux sciences se sont réunies, elles se sont prêteés des forces mutuelles, et ont marché ensemble d'un pas rapide vers la perfection.

LAGRANGE.

IN the preface to the new edition of the *Treatise on Quaternions* Professor Tait says, "It is disappointing to find how little progress has recently been made with the development of Quaternions. One cause, which has been specially active in France, is that workers at the subject have been more intent on modifying the notation, or the mode of presentation of the fundamental principles, than on extending the applications of the Calculus." At the end of the preface he quotes a few words from a letter which he received long ago from Hamilton— "Could anything be simpler or more satisfactory? Don't you feel, as well as think, that we are on the right track, and shall be thanked hereafter? Never mind when." I had the high privilege of studying under Professor Tait, and know well his single-minded devotion to exact science. I have always felt that Quaternions is on the right track, and that Hamilton and Tait deserve and will receive more and more as time goes on thanks of the highest order. But at the same time I am convinced that the notation can be improved; that the principles require to be corrected and extended; that there is a more complete algebra which unifies Quaternions, Grassmann's method and Determinants, and applies to physical quantities in space. The guiding idea in this paper is generalization. What is sought for is an algebra which will apply directly to physical quantities, will include and unify the several branches of analysis, and when specialized will become ordinary algebra. That the time is opportune for a discussion of this problem is shown by the recent dis-

cussion between Professors Tait and Gibbs in the columns of *Nature* on the merits of Quaternions, Vector Analysis, and Grassmann's method; and also by the discussion in the same Journal of the meaning of algebraic symbols in applied mathematics.

A student of physics finds a difficulty in the principle of Quaternions which makes the square of a vector negative. Hamilton says, *Lectures*, page 53, "Every line in tri-dimensional space has its square equal to a negative number, which is one of the most novel but essential elements of the whole quaternion theory." Now, a physicist is accustomed to consider the square of a vector quantity as essentially positive, for example, the expression $\frac{1}{2} mv^2$. In that expression $\frac{1}{2} m$ is positive, and as the whole is positive, v^2 must be positive; but v denotes the velocity, which is a directed quantity. If this is a matter of convention merely, then the convention in quaternions ought to conform with the established convention of analysis; if it is a matter of truth, which is true?

The question is part of the wider question—Is it necessary to take, as is done in quaternions, the scalar part of the product of two vectors negatively? I find that not only can problems, involving products of vectors, be worked out without the minus, but that the expressions so obtained are more consistent with those of algebra. Let, for example (fig. 1), **A** denote a vector of length a and direction α, and **B** another vector of length b and direction β, their sum is $\mathbf{A} + \mathbf{B}$, and the square of their sum I take to be $a^2 + 2ab \cos \alpha\beta + b^2$, where $\cos \alpha\beta$ denotes the cosine of the angle between the directions α and β. Suppose **B** to change until its direction is the same as that of **A**, the above expression becomes $a^2 + 2ab + b^2$, which agrees with the expression in algebra. But the quaternion method makes it $-(a^2 + 2ab + b^2)$. The sum of **A** and the opposite of **B** is $\mathbf{A} - \mathbf{B}$; its square is $a^2 - 2ab \cos \alpha\beta + b^2$ which becomes $a^2 - 2ab + b^2$, when **A** and **B** have the same direction, but according to quaternions it is $-a^2 + 2ab - b^2$.

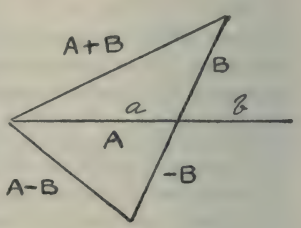

FIG. 1.

In ordinary algebra there are two kinds of quantity, the arithmetical or signless quantity, and what is called the algebraic quantity. The former (fig. 2), can be adequately represented on a straight line produced indefinitely in one direction from a fixed point. All the additive quantities are laid off end to end, and from the final point the subtractive quantities are laid off end to end, but in the opposite direction. The final point must stop short of the origin, in order that the result may be possible, under the supposition that the quantity is signless. But the algebraic quantity requires for its representation (fig. 3), a straight line produced

FIG. 2.

FIG. 3.

indefinitely in either direction from the fixed point. It is a directed quantity, which may have one or other of two directions. But though this quantity has a sign, its square is signless, or essentially positive. Hence only a positive quantity has a square root, and that root is ambiguous, on account of the two directions which the algebraic quantity may have. The generalization of this for space is that the square of any directed quantity is essentially positive, and that the square root of a signless quantity is entirely ambiguous as regards direction.

There is a want of harmony between the notation of Quaternions and that of Determinants. Let, as usual,

$\alpha = x\,i + y\,j + z\,k, \qquad \beta = x'\,i + y'\,j + z'\,k, \qquad \gamma = x''\,i + y''\,j + z''\,k,$

then

$$S\alpha\beta\gamma = -\begin{vmatrix} x & y & z \\ x' & y' & z' \\ x'' & y'' & z'' \end{vmatrix}$$

Would it not be simpler, if the scalar of α, β, γ, which has the same geometrical meaning as the determinant, had also the same sign? The inconsistency in sign arises from taking the scalar negatively and from taking the positive order of the vectors in the product to be from right to left. The positive order ought to be that of the natural order in writing, namely, from left to right, and from top to bottom. And why is it that only this determinant appears in quaternions while the whole series appears in the *Ausdehnungslehre?*

Another associated question is — Why is ∇^2 equal not to Laplace's operator but to the negative of it? Given the definition of ∇ as meaning $\frac{d}{dx}\,i + \frac{d}{dy}\,j + \frac{d}{dz}\,k$, does it follow necessarily that $\nabla^2 = -\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}\right)$? I have nowhere seen a reason given for the introduction of the minus, excepting one drawn from the analogy to the supposed negative square of a vector. If it is neither untrue, nor inconsistent, it would certainly be simpler to have

$$\nabla^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}.$$

In Thomson and Tait's *Natural Philosophy*, vol. I, p. 178, ∇^2 is defined as equal to Laplace's operator; also in other works, as Lamb's *Hydrodynamics*, and Ibbetson's *Mathematical Theory of Elasticity*. In Clerk Maxwell's *Electricity and Magnetism*, vol. II, p. 237, it is defined negatively; but in a footnote it is stated that the negative sign is employed to make the expressions consistent with those in which quaternions are employed. As further examples of this anomaly I may instance $du = -Sd\rho\,\nabla u$, and $\nabla\rho = -3$.

The investigation of this question means the investigation of the funda-

mental rules of quaternions. These we find in the rules for the combination of the symbols i, j, and k, namely:

$$jk = i \qquad ki = j \qquad ij = k$$
$$kj = -i \qquad ik = -j \qquad ji = -k$$
$$i^2 = -1 \qquad j^2 = -1 \qquad k^2 = -1$$

In the preface to his *Lectures* Hamilton narrates how, in his search for the extension to space of the imaginary algebra of the plane, he arrived at these rules, and how having formulated and partly tested them he felt that the new instrument for applying calculation to geometry had been attained. How are these rules established, not as properties of symbols, but as truths in geometry and physics? Writers on quaternions illustrate them by two different things—the summing of angles in space, and the rotation of a line about an axis. Let (fig. 4) i, j, k, denote three mutually perpendicular axes which are usually designated as the axes of x, y and z. In order to distinguish clearly between an axis and a quadrant of rotation about the axis, let $i^{\frac{\pi}{2}}, j^{\frac{\pi}{2}}, k^{\frac{\pi}{2}}$ denote quadrants of rotation in the positive direction about the respective axes. The directions of positive rotation are indicated by the arrows. Now in quaternions by $k^{\frac{\pi}{2}} j^{\frac{\pi}{2}}$ is meant (the $\frac{\pi}{2}$ is not expressed explicitly) a quadrant of the great circle round j followed by a quadrant of the great circle round k; the sum of these is the quadrant from k to j, which is the negative of a quadrant round i or $i^{\frac{3\pi}{2}}$; or it may be considered as a quadrant round $-i$, and therefore denoted by $-i^{\frac{\pi}{2}}$. Hence, supposing the order of the summing to be from right to left,

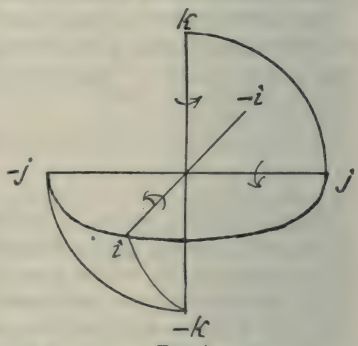

FIG. 4.

$$k^{\frac{\pi}{2}} j^{\frac{\pi}{2}} = -i^{\frac{\pi}{2}}, \qquad i^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = -j^{\frac{\pi}{2}}, \qquad j^{\frac{\pi}{2}} i^{\frac{\pi}{2}} = -k^{\frac{\pi}{2}}.$$

Again (see fig. 4) by $j^{\frac{\pi}{2}} k^{\frac{\pi}{2}}$ is meant a quadrant of the great circle round k followed by a quadrant of the great circle round j; this is equivalent to the quadrant from $-j$ to $-k$, which is a quadrant of the great circle round i and in the positive direction; hence, $j^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = i^{\frac{\pi}{2}}$ and similarly $k^{\frac{\pi}{2}} i^{\frac{\pi}{2}} = j^{\frac{\pi}{2}}$ and $i^{\frac{\pi}{2}} j^{\frac{\pi}{2}} = k^{\frac{\pi}{2}}$.

By $i^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}}$ is meant the sum of two quadrants of the great circle round i; it is equivalent to a semicircle round i; hence $i^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}} = i^{\pi}$. But as any one of the semicircles round i (for example, the one from j to $-j$ in the positive direction), is equivalent to any one of the semicircles joining the same points, the axis of $i^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}}$ is not restricted to i, but may be any axis whatever. Let such indefinite axis be denoted by ξ; then $i^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}} = \xi^{\pi}$ and this is what is denoted by -1. Similarly $j^{\frac{\pi}{2}}\,j^{\frac{\pi}{2}} = \xi^{\pi} = -1$; and $k^{\frac{\pi}{2}}\,k^{\frac{\pi}{2}} = \xi^{\pi} = -1$. Thus the minus comes in from the repetition of a quadrantal versor, and it is itself a versor with an indefinite axis. If the order of the versors and the order of writing are identified, the rules are

$$j^{\frac{\pi}{2}}\,k^{\frac{\pi}{2}} = -i^{\frac{\pi}{2}} \qquad k^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}} = -j^{\frac{\pi}{2}} \qquad i^{\frac{\pi}{2}}\,j^{\frac{\pi}{2}} = -k^{\frac{\pi}{2}}$$

$$k^{\frac{\pi}{2}}\,j^{\frac{\pi}{2}} = i^{\frac{\pi}{2}} \qquad i^{\frac{\pi}{2}}\,k^{\frac{\pi}{2}} = j^{\frac{\pi}{2}} \qquad j^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}} = k^{\frac{\pi}{2}}$$

$$i^{\frac{\pi}{2}}\,i^{\frac{\pi}{2}} = \xi^{\pi} = -1; \qquad j^{\frac{\pi}{2}}\,j^{\frac{\pi}{2}} = \xi^{\pi} = -1 \qquad k^{\frac{\pi}{2}}\,k^{\frac{\pi}{2}} = \xi^{\pi} = -1$$

If the process of finding the sum of two arcs of great circles is distributive, then by the application of the above rules, we can find the sum of any two quadrantal arcs. Let $li + mj + nk$ denote one axis, and $l'i + m'j + n'k$ another; then $(li + mj + nk)^{\frac{\pi}{2}}$ denotes a quadrant of the great circle round the former, and $(l'i + m'j + n'k)^{\frac{\pi}{2}}$ a quadrant of the great circle round the latter. The sum of the former and the latter in the order named is denoted by $(li + mj + nk)^{\frac{\pi}{2}}\,(l'i + m'j + n'k)^{\frac{\pi}{2}}$. If the rule of distribution holds, the sum is equal to

$$(li^{\frac{\pi}{2}} + mj^{\frac{\pi}{2}} + nk^{\frac{\pi}{2}})\,(l'i^{\frac{\pi}{2}} + m'j^{\frac{\pi}{2}} + n'k^{\frac{\pi}{2}})$$

$$= -(ll' + mm' + nn') + (mn' - nm')\,i^{\frac{\pi}{2}} + (nl' - ln')\,j^{\frac{\pi}{2}} + (lm' - ml')k^{\frac{\pi}{2}}$$

and by applying the rule of distribution in the reverse order

$$= -(ll' + mm' + nn') + \left\{(mn' - nm')\,i + (nl' - ln')\,j + (lm' - ml')k\right\}^{\frac{\pi}{2}}.$$

The first term has any axis, an angle π, and a multiplier $ll' + mm' + nn'$. The second term has an axis

$$\frac{(mn' - nm')\,i + (nl' - ln')\,j + (lm' - ml')\,k}{\sqrt{(mn' - nm')^2 + (nl' - ln')^2 + (lm' - ml')^2}}$$

an angle $\frac{\pi}{2}$ and a multiplier

$$\sqrt{(mn' - nm')^2 + (nl' - ln')^2 + (lm' - ml')^2}$$

These two terms together denote the arc of a great circle which is the sum of the two given arcs, its axis being the axis specified and its angle such that $-(ll' + mm' + nn')$ is its cosine.

We have next to consider the other meaning which is given to the fundamental rules: that they express the effect of a rotation on a line. Let $i\overset{\frac{\pi}{2}}{}j$ denote the turning by a quadrant round i of a line initially along j; and here I introduce the $\frac{\pi}{2}$ to denote explicitly what is meant by the first symbol. Hamilton obtains the same elementary rules as before, namely,

$$\begin{array}{lll} j\overset{\frac{\pi}{2}}{}k = i & k\overset{\frac{\pi}{2}}{}i = j & i\overset{\frac{\pi}{2}}{}j = k \\ k\overset{\frac{\pi}{2}}{}j = -i & i\overset{\frac{\pi}{2}}{}k = -j & j\overset{\frac{\pi}{2}}{}i = -k \\ i\overset{\frac{\pi}{2}}{}i = -1 & j\overset{\frac{\pi}{2}}{}j = -1 & k\overset{\frac{\pi}{2}}{}k = -1 \end{array}$$

or, to speak more correctly, the first six are obtained, while the remaining three are assumed. A quadrant rotation round j (see fig. 4) changes a line originally along k to a line along i; hence the direction denoted by $j\overset{\frac{\pi}{2}}{}k$ is identical with the direction i. Similarly, for the other two equations of the first set. A quadrant rotation in the positive direction round k turns a line originally along j to a line in the direction opposite to i; hence $k\overset{\frac{\pi}{2}}{}j = -i$. Similarly for the other two equations of the second set.

If we keep to the same meaning of the symbols as before, $i\overset{\frac{\pi}{2}}{}i$ ought to mean the effect of a quadrant rotation round i upon a line in the direction of i; and as that produces no change, we ought to have $i\overset{\frac{\pi}{2}}{}i = i$. Similarly $j\overset{\frac{\pi}{2}}{}j = j$ and $k\overset{\frac{\pi}{2}}{}k = k$. It follows that the true meaning of the rules lies in the summing of versors or arcs of great circles, and not in the rotation of a line.

This will be seen more clearly when we attempt to form the product of a quadrantal rotation round any axis and any line. Let $li + mj + nk$ denote the axis α (fig. 5), round which there is a quadrant of rotation, and $xi + yj + zk$ the line $\mathbf{R}$ which is turned. If the distributive rule applies, we get the result by decomposing the quadrant rotation round the given axis into the sum of three component rotations

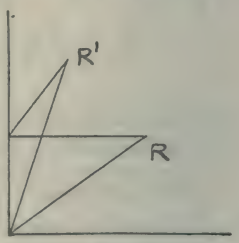

FIG. 5.

$$li\overset{\frac{\pi}{2}}{} + mj\overset{\frac{\pi}{2}}{} + nk\overset{\frac{\pi}{2}}{}$$

and finding their several effects on the several components of the line $xi+yj+zk$. According to the quaternion rules we obtain $-(lx+my+nz)+(mz-ny)\,i+(nx-lz)\,j+(ly-mx)\,k$. Now this expression is not the expression for the resulting line, or for any line, unless $lx+my+nz=0$. What is the true expression? It is $(lx+my+nz)\,(li+mj+nk)$ which is the component along the axis, and $(mz-ny)\,i+(nx-lz)\,j+(ly-mx)\,k$ is the expression for the other component, which is perpendicular to the axis and the initial line. The argument here is, of course, not so much about the proper expression for the result of the rotation, as about the meaning of the fundamental rules.

To make the rules which are true for versors applicable to vectors, it is necessary to identify a vector of unit length with a quadrantal versor having the same axis. In the new edition of his *Elements*, p. 46, Prof. Tait makes the transition from versors to vectors thus "One most important step remains to be made. We have treated i, j, k simply as quadrantal versors, and **i, j, k** as unit-vectors at right angles to each other, and coinciding with the axes of rotation of these versors. But if we collate and compare the equations just proved, we have $i^2=-1$, $\mathbf{i}^2=-1$, § 9; $ij=k$ and $i\mathbf{j}=\mathbf{k}$; $ji=-k$ and $j\mathbf{i}=-\mathbf{k}$. Now the meanings we have assigned to i, j, k are quite independent of, and not inconsistent with, those assigned to **i, j, k**. And it is superfluous to use two sets of characters when one will suffice. Hence it appears that i, j, k may be substituted for **i, j, k**; in other words, *a unit-vector when employed as a factor may be considered as a quadrantal versor whose plane is perpendicular to the vector.* Of course, it follows that every vector can be treated as the product of a number and a quadrantal versor. This is one of the main elements of the singular simplicity of the quaternion calculus."

By i is here meant what we have designated by $i^{\frac{\pi}{2}}$ and by **i** a unit-vector along the axis of i. We have already seen one difficulty opposing the identification, namely, taking as a principle that $i^{\frac{\pi}{2}}\,i=-1$. But waiving that insuperable objection, there still remains for consideration the case of the combination of two vectors. This kind of product, in which both factors are vectors, has in recent times been generally neglected. This is evident from what is said by Clifford (Mathematical papers, p. 386) "In every equation we must regard the *last* symbol in every term as either a vector or an operation; but all the others must be regarded as operations." This view does not explain the product of physical quantities.

Let xi, yj, zk denote line-vectors along the axes of i, j, k respectively; then according to the principles of quaternions

$$\begin{array}{lll} (yj)\,(zk)=yzi & (zk)\,(xi)=zxj & (xi)\,(yj)=xyk \\ (zk)\,(yj)=-yzi & (xi)\,(zk)=-zxj & (yj)\,(xi)=-xyk \\ (xi)\,(xi)=-x^2 & (yj)\,(yj)=-y^2 & (zk)\,(zk)=-z^2. \end{array}$$

As the distributive principle is to be applied, the meaning of these partial products must be such that the product of any two vectors is obtained

by taking the products of the several components of the one with the several components of the other.

Let $yjzk$ denote or be represented (fig. 6) by the rectangle included between yj and zk; its magnitude is yz and its orientation is defined by jk. But in space of three dimensions the aspect or orientation jk may be represented so far as direction is concerned by the complementary axis i. Hence we may write $yjzk = yzjk = yzi$. Similarly, $zkxi = zxki = zxj$ and $xiyj = xyij = xyk$. The expression $zykj$ denotes the same area in magnitude and plane as $yzjk$, but is taken the opposite way round; the complementary axis is $-i$. In the same sense $ik = -j$ and $ji = -k$. So far, the quaternion rules appear to hold good but even here, a difficulty appears on closer consideration. We have taken the vectors in the order of writing and obtain $jk = i$; if, as was pointed out, we take the versors also in the order of writing we obtain $j^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = -i^{\frac{\pi}{2}}$.

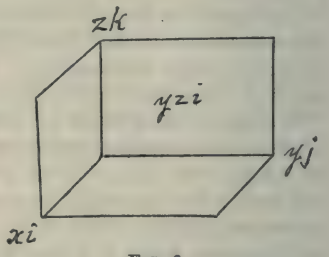

FIG. 6.

The question remains: What consistent meaning must be attached to $xixi$ and $yjyj$ and $zkzk$ in order that when they are taken along with the other partial products we may obtain a complete distributive product? The view which I have arrived at is that the expression $xixi = x^2i^2$ means the area of the square which is formed by the projection of xi on its own direction; and that it is essentially positive. Similarly y^2j^2 and z^2k^2 are essentially positive, and the three terms are to be combined by arithmetical addition. Individually they have no direction, whether their sum has or not. Hence I take the rules to be $ii = +$, $jj = +$, and $kk = +$.

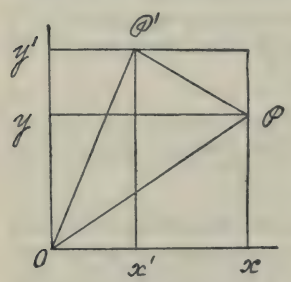

FIG. 7.

Let $\mathbf{R} = xi + yj + zk$ and $\mathbf{R}' = x'i + y'j + z'k$ be any two line-vectors. By applying the above rules distributively we obtain:

$$\mathbf{RR}' = (xi + yj + zk)\ (x'i + y'j + z'k)$$
$$= xx' + yy' + zz' + (yz' - zy')\ i + (zx' - xz')\ j + (xy' - yx')\ k.$$

Let OP and OP' be the projections of $\mathbf{R}$ and $\mathbf{R}'$ on the plane of i and j. Then from the figure (fig. 7) it is evident that the area of the triangle $OPP' = xy' - \frac{1}{2}xy - \frac{1}{2}x'y' - \frac{1}{2}(x - x')\ (y' - y) = \frac{1}{2}(xy' - yx')$

Thus $(xy' - yx')\ k$ denotes the magnitude and orientation of the parallelogram formed by the projections of $\mathbf{R}$ and $\mathbf{R}'$ on the plane of i and j. Similarly $(yz' - zy')\ i$ denotes the oriented area formed by the projections of

$\mathbf{R}$ and $\mathbf{R}'$ on the plane of j and k, and $(zx' - xz')\,j$ that for the plane of k and i. The geometrical sum of these areas is equal in magnitude and orientation to the area of the parallelogram formed in space by $\mathbf{R}$ and $\mathbf{R}'$, or rather the area formed by $\mathbf{R}$ and the component of $\mathbf{R}'$ which is perpendicular to $\mathbf{R}$.

The expression $xx' + yy' + zz'$ is the area formed by $\mathbf{R}$ and the projection of $\mathbf{R}'$ upon $\mathbf{R}$. For (fig. 8) the projection of $\mathbf{R}'$ is equal to ON, which is equal to $OL + LM + MN$, the sum of the projections on $\mathbf{R}$ of $x'i$, $y'j$ and $z'k$ respectively. Hence the product of $\mathbf{R}$ and the projection of $\mathbf{R}'$ is

$$r\left(x'\frac{x}{r} + y'\frac{y}{r} + z'\frac{z}{r}\right) = xx' + yy' + zz'$$

Hence by the complete product $\mathbf{RR}'$ we mean the product of $\mathbf{R}$ and the component of $\mathbf{R}'$ which is parallel to $\mathbf{R}$, together with the product of $\mathbf{R}$ and the component of $\mathbf{R}'$ which is perpendicular to $\mathbf{R}$. This product is distributive, that is, we get the same result whether we take the product directly, or take the several products of the components of $\mathbf{R}$ and $\mathbf{R}'$ and add them together, the non-directed products by ordinary addition, the directed products by geometrical addition. The expression $xx' + yy' + zz'$ is one of the fundamental expressions of the Cartesian analysis; the other term is expressed by the square root of the sum of the squares of its components, namely,

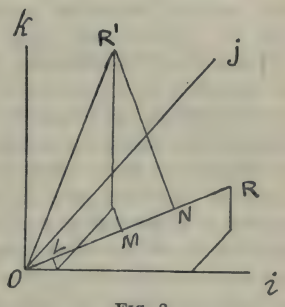

FIG. 8.

$$\sqrt{(yz' - zy')^2 + (zx' - xz')^2 + (xy' - yx')^2}$$

because that analysis does not provide an explicit notation for direction.

What reason do writers on quaternions give for taking $xx' + yy' + zz'$ negatively in the case of the product of two vectors? In the passage quoted above Professor Tait refers to section 9 of his *Treatise* for the proof that the square of a unit vector is -1. There we find: "It may be interesting, at this stage, to anticipate so far as to remark that in the theory of quaternions the analogue of $\cos\theta + \sqrt{-1}\,\sin\theta$ is $\cos\theta + \omega\,\sin\theta$, where $\omega^2 = -1$. Here, however, ω is not the algebraic $\sqrt{-1}$, but is any directed unit-line whatever in space."

In the above expression ω really means the versor $\omega^{\frac{\pi}{2}}$. The algebraic imaginary $\sqrt{-1}$ means, as is well known, a turning of $\frac{\pi}{2}$; what is indefinite about it is that the axis is not specified; and it must be supposed constant, if the rules about the manipulation of $\sqrt{-1}$ are to hold good.

The true reason for taking the expression negatively is to satisfy the rule of association. In the preface to his *Lectures*, p. 53, Hamilton shows that if the product

$$(xi+yj+zk)\ (x'i+y'j+z'k)\ (x''i+y''j+z''k)$$

is to satisfy the associative rule, as well as the distributive, and if the scalar part already obtained in the multiplication is to be treated as a mere number, then we must have

$$xix'i=-xx' \qquad yj\ y'j=-yy' \qquad zkz'k=-zz'$$

"On this plan every line in tridimensional space has its square equal to a negative number."

But what quantity in space possesses such associative and distributive properties? It is proved to be true of the summing of versors, that is, of arcs of great circles on a sphere, when the portion of the arc designated by the versor may be taken anywhere on the great circle (fig. 9). As any two great circles have a common line of intersection, the arcs may be moved along until the second starts from the end of the first, as AB and BC. The sum of AB and BC, denoted by $(AB)\ (BC)$ is equal to AC, the arc of the great circle which joins A and C. A third versor, as DE, will not in general pass through A or C, but it will meet the great circle AC in some point as D. Shift AC back to FD; then the versor FE is the sum of FD and DE, and therefore the sum of AB, BC, DE. The associative property means, that if BC and DE are first summed and then AB with the result, the arc of the great circle so obtained will be equal in magnitude and on the same circle as the arc obtained by the former mode of procedure. The proof of the theorem is not simple; in Tait's *Elementary Treatise* it is accomplished by the help of the fundamental properties of the curves known as *Spherical Conics*, discovered only in recent times by Magnus and Chasles. Doubtless many a one has been discouraged from the study of quaternions by the abstruse nature of the fundamental principles.

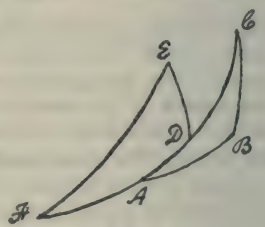

FIG. 9.

It is clear from the figure that the summing of versors cannot be adequately represented by a versor rotating a line at right angles to its axis. The versor AB followed by the versor BC may rotate a line non-conically from A to C, but the subsequent versor DE cannot in general operate in the same way upon the line at C. To do so, the great circle of DE must intersect the great circle of BC in the point C.

As the result of the investigation we conclude,

First, That the product of two vectors or directed magnitudes,

$$\mathbf{T}=pi+qj+rk \text{ and } \mathbf{S}=ui+vj+wk, \text{ is}$$

$$\mathbf{TS}=pu+qv+rw+(qw-rv)i+(ru-pw)j+(pv-qu)k.$$

Hence that there is a generalized product which includes the product of real quantities, such geometric products as are sometimes used in proving

the propositions of the second book of Euclid, the products of Grassmann's *Ausdehnungslehre*, determinants, and generally the products of physical magnitudes. By a physical magnitude I mean a symbol which represents not only ratio and direction but these combined with the physical unit. The corresponding generalized algebra forms a large complement of the algebra of physics.

Second, That the product of two quadrantal versors or geometric ratios

$r = (xi + yj + zk)^{\frac{\pi}{2}}$ and $r' = (x'i + y'j + z'k)^{\frac{\pi}{2}}$ is

$$rr' = -(xx' + yy' + zz') - \left\{ (yz' - zy')i + (zx' - xz')j + (xy' - yx')k \right\}^{\frac{\pi}{2}}$$

Hence that there is a generalized product which includes the product of ratios, and the product of complexes, and which is the special subject of analytical trigonometry, spherical trigonometry and the method of quaternions.

Third, The effect of a quadrantal rotation $(li + mj + nk)^{\frac{\pi}{2}}$ upon a line $xi + yj + zk$ is

$$(lx + my + nz)(li + mj + nk) + (mz - ny)i + (nx - lz)j + (ly - mx)k.$$

The subject of rotation and the effect of rotation on a line may be considered as belonging to the versor part of the algebra of space. The effect of a rotation of any angle upon a line is still more complex, and does not answer to the definition of a product as a distributive function.

Before the time of DesCartes, an algebraic quantity was represented by a line, the product of two quantities by the rectangle formed by the lines, the product of a quantity by itself as the square formed by the line, the product of three quantities by the right solid formed by the lines, which when the lines were equal, became the cube. Each term of a cubic equation was interpreted as denoting a solid, and the equation was actually solved by cutting up a cube. In order to explain higher powers than the cube, space of four or any adequate number of dimensions was imagined. This concrete view of a product corresponds to the vector part of generalized algebra.

The doctrine of DesCartes was that the algebraic symbol did not represent a concrete magnitude, but a mere number or ratio, expressing the relation of the magnitude to some unit. Hence that the product of two quantities is the product of ratios, and instead of being represented by a rectangle may be represented in the same way as either factor; that the powers of a quantity are ratios like the quantity itself, and therefore there is no need of imagining space of more than one dimension. This view of a product corresponds to the versor part of the generalized algebra.

The theory here advanced will be elaborated and developed in the pages which follow; but before proceeding to that development, I propose to consider several other objections which have been or may be made against the various methods of extending algebra to quantities in space, with the view of discussing their validity; and, if they appear to be valid, whether they are removed by the theory advanced.

Some mathematicians have objected to the negative character of the scalar in the product of two vectors. In the recent discussion in the columns of *Nature* (Vol. XLIII, p. 511), Professor Gibbs says, "When we come to functions having an analogy to multiplication, the product of the lengths of two vectors and the cosine of the angle which they include, from any point of view except that of the quaternionist, seems more simple than the same quantity taken negatively. Therefore we want a notation for what is expressed by $-S\alpha\beta$ rather than $S\alpha\beta$ in quaternions." This agrees with the theory here advanced. But I do not look upon the product of two vectors as merely having an analogy to muliplication, but as multiplication itself generalized.

It has been objected that while the scalar product and the vector product are each of primary importance, the quaternion proper which is their sum, is of very secondary importance. Thus, Professor Hyde, in a paper on the "Calculus of Direction and Position" (*Amer. Journ. of Math.*, Vol. VI, p. 3), says, "The combination of these different functions in the vector renders the product of two vectors which are neither parallel nor perpendicular to each other necessarily a complex quantity, having a scalar and a vector part corresponding to the real and imaginary parts of the ordinary complex $a+b\sqrt{-1}$, thus making a thing which should be simple just the opposite. It seems to me that quaternions proper, *i. e.*, these complex quantities, are practically of little use. In nearly all the applications to geometry and mechanics, scalars and vectors are used separately. For the special cases to which the complex $a+b\sqrt{-1}$ is put, the directed quantity is not needed."

In reply it may be said that the works of Hamilton and Tait make it abundantly evident that the quaternion idea is essential to the algebraic treatment of spherical trigonometry and of rotations. As regards the use of the complex $a+b\sqrt{-1}$, it is indefinite, unless restricted to a plane. It is shown in the development which follows that when the axis is introduced, many of the known theorems in trigonometry can be greatly extended, and that the entire meaning of the formulæ becomes evident as truths in geometry, not mere consequences from the conventional use of symbols.

In the letter to *Nature* quoted above, Professor Gibbs urges the same objection. "The question arises whether the quaternionic product can claim a prominent and fundamental place in a system of vector analysis. It certainly does not hold any such place among the fundamental geometrical conceptions as the geometrical sum, the scalar product, or the vector product. The geometrical sum $\alpha+\beta$ represents the third side of a triangle as determined by the sides α and β. $V\alpha\beta$ represents in magnitude the area of the parallelogram determined by the sides α and β, and in direction the normal to the plane of the parallelogram. $S\gamma V\alpha\beta$ represents the volume of the parallelopiped determined by the edges α, β and γ. These conceptions are the very foundations of geometry. We may arrive at the same conclusion from a somewhat narrower but very practical

point of view. It will hardly be denied that sines and cosines play the leading parts in trigonometry. Now, the notations $V\alpha\beta$ and $S\alpha\beta$ represent the sine and cosine of the angle included between α and β combined in each case with certain other simple notions. But the sine and cosine combined with these auxiliary notions are incomparably more amenable to analytical transformation than the simple sine and cosine of trigonometry, exactly as numerical quantities combined (as in algebra) with the notion of positive or negative quality are incomparably more amenable to analytical transformation than the simple numerical quantities of arithmetic. I do not know of anything which can be urged in favor of the quaternionic product of two vectors as a *fundamental* notion in vector analysis, which does not appear trivial or artificial in comparison with the above considerations. The same is true of the quaternionic quotient and of the quaternion in general."

It may be observed that Professor Gibbs does not give the geometrical meaning of $S\alpha\beta$ but that of $S\alpha V\beta\gamma$. The geometrical meaning given to the latter cannot be transferred to the former. They may have a common meaning when α, β, γ denote quadrantal versors, but the common meaning is not so evident when α, β, γ denote vectors. The meaning which I attach to $V\alpha\beta$ is not, strictly speaking, the area of the parallelogram determined by the sides α and β, for then from the symmetry of the idea there would be nothing to determine the positive sign; it rather is the area formed by α and the component of β which is perpendicular to α; and as a complement we have the area formed by α and the component of β which is parallel to α. If α and β are both of unit length or, rather, if we consider their direction apart from their physical magnitude, $V\alpha\beta$ expresses the sine and $S\alpha\beta$ the cosine of the angle between the directions α and β; and in this case the product $\alpha\beta$ denotes the angle between α and β. But it is of the greatest importance that the angle should be treated as a whole, not merely the sine part separately and the cosine part separately. Thus, the argument from trigonometry leads to the opposite conclusion to that at which Professor Gibbs arrives.

It seems to me that the essence of a product is that it is a distributive function of the factors. Thus in ordinary algebra $(a+b+c)(a'+b'+c') = aa' + bb' + cc' + bc' + cb' + ca' + ac' + ab' + ba'$. We have nine partial products, and in my view the product of two quantities, each consisting of three parts, is not complete, unless it contains the nine partial products; otherwise, the product is not a generalization of the product of ordinary algebra. As a consequence of not treating together the two complementary parts of the product of two vectors, Grassmann and his followers have restricted their attention to associative products and treat of these only in a detached manner. In treating of the product of a number of vectors, that is a very arbitrary principle which holds that all the terms into which two similar directions enter must vanish; but that is a principle of the *Ausdehnungslehre* and of determinants.

Are the principles of the method of quaternions consistent with the theory of dimensions which has played so important a part in mathematical physics since the time of Fourier? Do they remove Gregory's difficulty as to how areas and solids can be represented by the apparent multiplication of lines? Professor Hyde, in the preface to the *Directional Calculus*, a valuable text-book on Grassmann's method, states that Grassmann's system is founded on and absolutely consistent with the idea of geometric dimensions, while Hamilton's is not. We find this objection amplified in the paper referred to, *Am. Jour. Math.*, Vol. VI, p. 3. "From this assumption it follows as above, that $ij = k$ and also that $i/j = -ij = -k$, *i. e.*, the ratio of two quantities is the same thing as their product except as to sign. To be sure we may say that these are units, and we have the analogy that $1/1 = 1 \times 1$; but they, *i. e.*, vectors, are geometric and directed units, and such a relation appears to me to upset all one's preconceived ideas of geometric quantities without any corresponding advantage. If, in the equation $1/1 = 1 \times 1$, 1 be taken as the unit of length, then the members of the equation have evidently not the same meaning, $1/1$ being merely a numerical quantity, while 1×1 is a unit of area, it being a fundamental geometrical conception that the product of a length by a length is an area, that of a length by an area a volume, while the ratio of two quantities of the same order as that of a length to a length is a mere number of the order zero. In quaternions, however, we have the remarkable result that the product of a length by a length is not merely represented by, but actually equal to a length perpendicular to the plane of the two."

This objection is not valid against the method of quaternions as the algebra of versors or directed quotients, that is, geometric ratios; but it is valid against it as claiming to be the algebra of vectors or physical magnitudes. The primary definition of the quaternion is the quotient, not the product, of two directed lines. "From the purely geometrical point of view, a quaternion may be regarded as the quotient of two directed lines in space, or what comes to the same thing as the factor or operator which changes one directed line into another," *Ency. Brit.*, Art. *Quaternions*. The latter definition, as we have seen, is not exactly the same thing as the former; the former is the primary and true definition. The product of two vectors is derived analytically from the quotient of two vectors; no geometric meaning is attached to it as a whole, but it is interpreted as a quaternion. Thus, Hamilton, *Elements*, p. 303: "We proceed to consider, in the following section some of the general consequences of this definition, or interpretation of a product of two vectors, as being equal to a certain quotient or quaternion."

If the product of two vectors is a quaternion, then the definition of a quaternion as the quotient of two lines is not correct. But this confusion vanishes when the product of two vectors is perceived to be distinct from and independent of that of two versors. The directed part of a versor, or of any number of versors is not a line in the sense of involving the unit of length; it is of zero dimensions like the ordinary sine of trigonometry. A directed term in the product of vectors may be of one, two, three or any number of dimensions in length. A quantity having three

dimensions in length is not necessarily a scalar, nor is it true that a directed quantity is necessarily of one dimension in length. The idea of an axis is different from the idea of a directed line of unit length. I look upon the symbols i, j, k as denoting not a unit-vector, but direction simply, the idea contained in the word *axis*. In writing $ij = k$, we do not equate a product of lines to a line, but the axis denoted by ij to the axis k. In space of four dimensions this equation is not true; it depends for its truth on the tridimensional character of space. In such an expression as xi it is more philosophical and correct to consider the x as embodying the unit, while i denotes simply the axis. I look upon the magnitude as containing the physical unit, to be arithmetical ratio and unit combined; and different vectors have different physical units. A line is a vector which has length for unit; a linear velocity involves length directly and time inversely; momentum involves mass and length directly and time inversely. An axis is not a physical quantity, but merely a direction. It follows from the theory of vector-algebra here advanced that the reciprocal of a vector has the same axis as the vector but the reciprocal magnitude. As the dimensions depend on the magnitude not on the axis, it follows that

$$ij = \frac{1}{i} j = i \frac{1}{j} = \frac{1}{i} \frac{1}{j} = k;$$

that is, the axis of the term which involves i and j, or of the term which involves one directly and one reciprocally, or of the term which involves both reciprocally is k.

It appears to me that this same principle of dimensions is not observed strictly in Grassmann's method or in the "Directional Calculus." We meet such an equation as $p_2 = p_1 + \varepsilon$ where p_1 and p_2 denote points and ε denotes a vector. Notwithstanding that a point is of zero dimensions and ε is used to denote a line-vector, we have a point equated to the sum of a point and a line. That ε is of one dimension in length is evident, for the expression $\varepsilon_1\varepsilon_2$ denotes the area of a parallelogram, and $\varepsilon_1\varepsilon_2\varepsilon_3$ denotes the volume of a solid, while $\varepsilon\mathfrak{F}$ denotes the moment of a force. It appears that either the equation is heterogeneous, or else p_1 and p_2 must be understood as denoting vectors from some common point; if the latter view is correct, the point-analysis reduces to a vector-analysis. From the physical point of view it is more correct to treat of a mass-vector than of a point having weight; for the differential coëfficient with respect to time of a mass-vector is the momentum, which is itself a mass-vector. If the latter is of one dimension in length, so is the former. The product of a point and a mass is not a physical idea.

Professor Hyde indicates another element in which Grassmann's method appears superior to Hamilton's. "Now quaternions deal only with the vector or line direction and the scalar — for a quaternion is only the sum of these two; it knows nothing of a vector having a definite position, which is the complete representation of the space qualities of a force." This is the distinction which Clifford emphasized between a vector which may be anywhere and one which is restricted to a definite line; to dis-

tinguish the latter from the former he introduced the word *rotor*, short for rotator, the velocity of rotation being a typical localized vector. The contrast between vector and rotor is of great importance, and it is convenient to have a notation which specifies a rotor completely as depending on two vectors. In the works of Hamilton and Tait a force is specified by two vectors, as α and ρ, the former denoting the magnitude and direction of the force, the latter the vector from an origin to the point of application. That which is denoted in quaternions by ρ is denoted in Grassmann's method by p, and it appears that p is equivalent to the vector from an origin.

The method of Grassmann is applicable, so far as it goes, to space of n dimensions, while the method of Hamilton appears to be restricted to space of three dimensions. How is it possible to unify the two and develop an algebra not only of three dimensional space but of four dimensional space? Professor Hyde, in his preface, says, "As the great generality of Grassmann's processes — all results being obtained for n-dimensional space—has been one of the main hindrances to the general cultivation of his system, it has been thought best to restrict the discussion to space of two or three dimensions . . . It seems scarcely possible that any method can ever be devised, comparable with this, for investigating n-dimensional space."

On this subject Professor Gibbs says, *Nature*, Vol. XLIV, p. 82, "Such a comparison (of Hamilton's and of Grassmann's systems) I have endeavored to make, or rather to indicate the basis on which it may be made, so far as systems of geometrical algebra are concerned. As a contribution to analysis in general, I suppose that there is no question that Grassmann's system is of indefinitely greater extension, having no limitation to any particular number of dimensions." Also in *Nature*, Vol. XLIII, p. 512, "How much more deeply rooted in the nature of things are the functions $S\alpha\beta$ and $V\alpha\beta$ than any which depend on the definition of a quaternion, will appear in a strong light, if we try to extend our formulæ to space of four or more dimensions. It will not be claimed that the notions of quaternions will apply to such a space, except indeed in such a limited and artificial manner as to rob them of their value in a system of geometrical algebra. But vectors exist in such a space, and there must be a vector analysis for such a space." In reply Professor Tait said, "It is singular that one of Professor Gibbs' objections to quaternions should be precisely what I have always considered (after perfect inartificiality) their chief merit, viz., that they are *uniquely adapted to Euclidian space*, and therefore specially useful in some of the most important branches of physical science. What have students of physics, as such, to do with space of more than three dimensions?"

The view which I have arrived at, unifying Hamilton and Grassmann and developing a more comprehensive algebra is: That $i^2 = +\quad j^2 = +\quad k^2 = +$ do not involve the condition of three dimensions, being true for space of any number of dimensions, while $ij = k\quad jk = i\quad ki = j$ do involve and indeed express the condition of three dimensions. The rules $ij = -ji\quad jk = -kj\quad ki = -ik$ are also true generally. In space of four

dimensions we require four mutually rectangular axes; let the fourth be denoted by u. Then it is not true that $ij = k$; but it is true that $ijk = u$, $jku = -i$, $kui = j$, $uij = -k$.

A difficulty has been felt in the apparent heterogeneity of a sum of scalar and vector terms. Hamilton was never quite satisfied, and speculated on an extraspatial unit. Now, the heterogeneity is not in dimensions, for all the terms have the same number of dimensions with respect to each unit involved in the units of the factor-vectors. The theory of axes here advanced and the extension of algebra to space of four dimensions show that all the terms are homogeneous in the sense of having an axis, but that for some terms it may be any axis; for others, the fourth axis in a space of four dimensions.

DEFINITIONS AND NOTATION.

I propose to use a notation which shall conform as far as possible with the notation of algebra, the Cartesian analysis, quaternions, etc., but shall at the same time embody what I conceive to be the principles of the algebra of physics. The most logical procedure is to generalize as far as possible the notation of algebra.

By an *arithmetical* quantity is meant an essentially positive or signless quantity; it has no direction or any direction. For example, the mass of a body, or its kinetic energy.

By a *scalar* is meant a quantity which has magnitude, and may be positive or negative, but is destitute of a definite axis; or it is the element of a physical quantity which is independent of the axis. It is equivalent to the ordinary algebraic quantity, and is denoted, as usual, by an Italic letter as a, b, x, X, etc. The work done by or against a force, and the volume of a geometric figure are examples. These quantities, though both scalar, differ in dimensions, and they are scalars for different reasons.

By a *vector* is meant a quantity which has magnitude and an axis. It requires three numbers to specify it completely. The simplest example is the displacement of a point, represented by a straight line drawn from its original to its final position. Other examples are a linear velocity, an area in a plane, and a current of fluid. These several quantities differ in dimensions and in the nature of the physical unit; and there are vectors which have the same dimensions in length, yet have different kinds of axes. What they have in common is a want of symmetry in space.

A vector is denoted by a black capital letter as $\mathbf{A}$, its magnitude by a and its axis by α. Thus $\mathbf{A} = a\alpha$, $\mathbf{B} = b\beta$, $\mathbf{R} = r\rho$. Sometimes it is necessary to introduce a dot to separate the expression for the magnitude from the expression for the direction; but when the two symbols are single, as in $a\alpha$, the dot may be omitted. The difference of type shows that a denotes the algebraic magnitude and α merely its axis, not another algebraic magnitude. In Clerk-Maxwell's *Electricity and Magnetism*, German capitals are used to denote vectors, but these are difficult to make, and plain black letters have already been used for the purpose, as by Fleming in his book on *Alternate Current Transformers*. The simple a and α are more commodious than Ta and Ua as used in works on quaternions,

and the notation is also more in harmony with the Cartesian analysis. What is done is merely to introduce α to specify the axis in space, leaving the expression for the scalar part of the magnitude the same as before. In the case of mutually rectangular components, i, j and k are used to denote the axes.

Vector quantities may be classified according to the nature of the axis. By a line-vector is meant one which has a simple axis of direction,—a vector in the primary meaning of the word as used by Hamilton. It is of one dimension in length.

By the *pole* of two axes is meant the axis which is perpendicular to both. The pole of α and β is denoted by $\overline{\alpha\beta}$; the pole of $\overline{\alpha\beta}$ and γ is denoted by $\overline{\overline{\alpha\beta}\gamma}$; that of α and $\overline{\beta\gamma}$ by $\overline{\alpha\overline{\beta\gamma}}$ and so on. An axis which is perpendicular to α but otherwise indefinite, may be denoted by $\overline{\alpha}$. This notation enables us to express explicitly three mutually rectangular axes. Let α and β be any two independent axes; then, α and $\overline{\alpha\beta}$ and $\overline{\overline{\alpha\beta}\alpha}$ denote three mutually rectangular axes. In the works on quaternions, there is no systematic notation for direction; consequently to specify the axis which is perpendicular to two given axes, it is necessary to use a special non-systematic symbol.

By a *tensor* is meant an arithmetical ratio or quantity destitute of dimensions and of axis. This is the primary meaning of the word as used by Hamilton; it is primarily used to denote the magnitude of the quaternion quotient defined as a ratio of two lines in space. To conceive a, b, x, X, etc., as tensors, is to suppose the unit thrown into the symbols i, j, k. It is certainly not convenient to regard i, j, k as denoting directed physical units; it is more philosophical, more practical, and more in harmony with mathematical analysis to regard them as axes, and a, b, x, X, etc., as magnitudes, not mere tensors.

By a *vector-scalar* is meant a scalar quantity which has position in space; for example, the physical quantity which Clerk Maxwell calls a *mass-vector;* it is proportional to the mass and to the vector from an origin to the mass. Such a quantity may be denoted by $\mathbf{A} \cdot m$, where the Italic letter denotes the scalar or signless quantity, and $\mathbf{A}$ denotes the vector from an origin to the position of the quantity. This idea corresponds to the weighted point of the *Ausdehnungslehre.*

By a *rotor* is meant a localized vector, or a vector-vector; it has magnitude, direction and position; for example, a force or a rotational velocity. It may be denoted by such a symbol as $\mathbf{A} \cdot \mathbf{F}$ where $\mathbf{A}$ denotes the vector from an origin to the point of application, and $\mathbf{F}$ denotes the vector quantity.

By a *versor* is meant an amount of arc of a great circle on the sphere; it has an axis and an amount of angle. A versor, as a whole, may be denoted by a small black letter as $\mathfrak{a}$, and analytically by α^A, where α denotes its axis, and A the amount of its angle in circular measure. Thus $\alpha^{\frac{\pi}{2}}$ is the imag-

inary $\sqrt{-1}$ for the axis a; while $a^{2\pi}$ is equivalent to the trigonometrical +, provided that in this case a denote any axis. I consider that it is more convenient, and more in harmony with trigonometry and the law of indices to consider $\frac{\pi}{2}$, not 1, as the index of a quadrantal versor.

By a *quaternion* is meant a geometric ratio; it is an ordinary arithmetical ratio, or tensor, combined with a versor. It is denoted by $a\alpha^A$, where a denotes the ratio and α^A the versor. The ratio and axis may be expressed synthetically as a vector-ratio **A**, giving the expression $\mathbf{A}^A$ for the quaternion.

By a *dyad* is meant a physical ratio, or the rate connecting two vector quantities, and these may involve different physical units. Let **S** denote the dependent vector, **R** the independent; if the former is directly proportional to the latter, the dependence is expressed by the rate $\mathbf{R}^{-1}\,\mathbf{S}$. Professor Gibbs in his *Vector Analysis* bases the treatment of vectors largely on the conception of a dyad; and the word, I believe, is due to him. The dyad is in a certain sense a localized quaternion; it has an axis and an angle, but the angle is localized, that is, it must start from a specific direction. There is also this difference, that the dyad generally has dimensions in its magnitude, while the quaternion quotient has not.

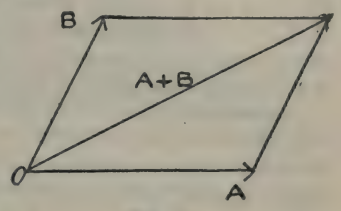

FIG. 10.

By a *matrix* is meant the sum of the rates connecting a vector quantity with the three independent components of another vector quantity. In its simplest form it is equivalent to a homogeneous strain or linear-vector operator. As it is a sum of dyads, Professor Gibbs calls it a *dyadic*. The synthetic symbol used to denote a matrix is a Greek capital letter as Φ.

ADDITION AND SUBTRACTION OF VECTORS.

Addition.—By adding two quantities of the same kind of vector quantity is meant finding their geometric resultant, or what is called in mechanics compounding them. This process is called addition, because when the vectors have a common axis, the process reduces to ordinary algebraic addition. Suppose two quantities of a vector **A** and **B** to have a common point of application *O* (fig. 10), their resultant or sum is the diagonal of the parallelogram of which **A** and **B** are the sides. The principle of the parallelogram of forces is thus one of the fundamental principles of the algebra of physics.

Subtraction. — By subtracting one quantity of a vector from another quantity is meant finding the quantity which added to the former produces the latter. Let **A** (fig. 11) be the quantity to be subtracted, and **B** the quantity to be subtracted from; the remainder is the vector from the end of **A** to the end of **B**, the cross-diagonal of the parallelogram formed by **A** and **B**, and taken in the direction from **A** to **B**.

To subtract a quantity of a vector is equivalent to reversing the axis and then adding. In the figure (fig. 11) $-\mathbf{A}$ is the opposite of $\mathbf{A}$ in direction; and the diagonal from the corner of the parallelogram formed by $-\mathbf{A}$ and $\mathbf{B}$ is equal to the cross-diagonal of the parallelogram formed by $\mathbf{A}$ and $\mathbf{B}$. To define subtraction as addition after reversal seems to me less accurate than to recognize the two processes of composition and resolution of vector quantities. Let a small minus before the $\mathbf{A}$ denote reversal of axis, while a large minus denotes subtraction, then we have the theorem or principle $\mathbf{B} - \mathbf{A} = \mathbf{B} + {}^{-}\mathbf{A}$. Hence we have the rules $-\mathbf{A} = +{}^{-}\mathbf{A}$ and $+\mathbf{A} = -{}^{-}\mathbf{A}$, which mean respectively: to subtract a quantity is equivalent to adding the opposite quantity; and to add a quantity is equivalent to subtracting the opposite quantity.

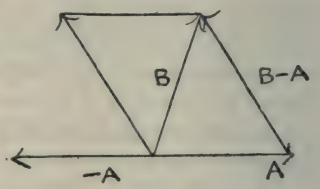

FIG. 11.

Commutative Rule.—When the point of application of a vector is indefinite, the sum of two quantities of it as $\mathbf{A}$ and $\mathbf{B}$ is the same, whether they are applied simultaneously, or $\mathbf{A}$ first and then $\mathbf{B}$, or $\mathbf{B}$ first and then $\mathbf{A}$. Hence the commutative rule in adding and subtracting quantities of a vector

$$\mathbf{A} + \mathbf{B} = \mathbf{B} + \mathbf{A}.$$

Associative Rule.—It follows from the commutative property that if a third quantity $\mathbf{C}$ is to be compounded, it is immaterial whether the sum of $\mathbf{A}$ and $\mathbf{B}$ be added to $\mathbf{C}$, or $\mathbf{A}$ be added to the sum of $\mathbf{B}$ and $\mathbf{C}$. Hence the associative rule in adding and subtracting quantities of a vector

$$(\mathbf{A} + \mathbf{B}) + \mathbf{C} = \mathbf{A} + (\mathbf{B} + \mathbf{C})$$

It follows that the rules for the transformation of equations between quantities of a vector by adding or subtracting equal terms on the two sides are the same as those in ordinary algebra, where the axis of all the terms is constant.

Given the magnitude and axis of each of the components; to find the magnitude and axis of the sum.

Given $\mathbf{A} = a\alpha$, and $\mathbf{B} = b\beta$;

then $\mathbf{A} + \mathbf{B} = a\alpha + b\beta$

$$= \sqrt{a^2 + b^2 + 2ab\cos\alpha\beta} \cdot \overline{\alpha\ \beta}^{\tan^{-1}\frac{b\sin\alpha\beta}{a + b\cos\alpha\beta}\,\alpha}$$

Here $\sqrt{a^2 + b^2 + 2ab\cos\alpha\beta}$ gives the magnitude of the sum, while the rest of the expression denotes its axis in terms of the given quantities. In that expression $\overline{\alpha\ \beta}$ denotes the axis, and $\tan.^{-1}\frac{b\sin\alpha\beta}{a + b\cos\alpha\beta}$ the angle of the versor which changes α into the direction of the sum.

For the generalized addition which applies to quantities of a scalar situated at different points or to quantities of a vector applied at different points, see the end of the paper.

PRODUCT OF TWO VECTORS.

Different forms of the product.—Let

$$\mathbf{A} = a_1 i + a_2 j + a_3 k$$

and

$$\mathbf{B} = b_1 i + b_2 j + b_3 k$$

be any two vector quantities, not necessarily of the same kind. Their product, according to the rules (p. 72), is

$$\begin{aligned}\mathbf{AB} &= (a_1 i + a_2 j + a_3 k)\,(b_1 i + b_2 j + b_3 k)\\ &= a_1 b_1 ii + a_2 b_2 jj + a_3 b_3 kk + a_2 b_3 jk + a_3 b_2 kj + a_3 b_1 ki + a_1 b_3 ik\\ &\quad + a_1 b_2 ij + a_2 b_1 ji;\\ &= a_1 b_1 + a_2 b_2 + a_3 b_3 + (a_2 b_3 - a_3 b_2)\, i + (a_3 b_1 - a_1 b_3)\, j\\ &\quad + (a_1 b_2 - a_2 b_1)\, k;\\ &= a_1 b_1 + a_2 b_2 + a_3 b_3 + \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ i & j & k \end{vmatrix}\end{aligned}$$

Here the vector part is written in the form of a determinant. In the Cartesian analysis this vector determinant is imperfectly expressed by means of the composite determinant

$$\left\| \begin{matrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{matrix} \right\|$$

Let **A** and **B** be given in the form $a\alpha$ and $b\beta$ respectively; then it is evident (from p. 72) that

$$a_1 b_1 + a_2 b_2 + a_3 b_3 = ab \cos a\beta;$$

and

$$\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ i & j & k \end{vmatrix} = ab \sin a\beta \cdot \overline{a\beta}$$

where $\overline{a\beta}$ is used to denote the axis which is perpendicular to α and β.

Hence

$$\begin{aligned}\mathbf{AB} &= ab \cos a\beta \cdot a\alpha + ab \sin a\beta \cdot \overline{a\beta}\\ &= ab\,(\cos a\beta + \sin a\beta \cdot \overline{a\beta}).\end{aligned}$$

Notation for the two parts of the product.—In quaternions the negative of $a_1 b_1 + a_2 b_2 + a_3 b_3$ is called the *scalar* of **AB** and is denoted by *S***AB**, while the other term is called the vector of **AB** and is denoted by *V***AB**. The objection to this notation is the association of the negative sign with the word scalar, and the want of a convenient notation for the magnitude of the vector part. As they are not linked to anything in ordinary algebra, they make the connection obscure and the transition difficult from ordinary algebra to the algebra of space.

I have found it convenient to use for this purpose the functional expressions *cos* and *Sin*. They possess all the advantage of a logical generalization; for when abstraction is made of the magnitude of the product they then have their trigonometrical meaning. They make the formulæ much more self-interpreting. Thus, we write

$$\mathbf{AB} = cos\,\mathbf{AB} + Sin\,\mathbf{AB},$$

Sin with a capital denoting the complete vector quantity, while *sin* denotes its magnitude irrespective of axis.

The product of two vectors is not, in general, commutative.—For

$$\mathbf{AB} = a_1b_1 + a_2b_2 + a_3b_3 + \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ i & j & k \end{vmatrix}$$

and

$$\mathbf{BA} = b_1a_1 + b_2a_2 + b_3a_3 + \begin{vmatrix} b_1 & b_2 & b_3 \\ a_1 & a_2 & a_3 \\ i & j & k \end{vmatrix}$$

$$= a_1b_1 + a_2b_2 + a_3b_3 - \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ i & j & k \end{vmatrix}$$

Hence, it is commutative only if $Sin\ \mathbf{AB} = 0$, that is if $\beta = \alpha$. This condition is satisfied by the quantities of ordinary algebra, but not by quantities in a plane.

Square of a vector.—Let $\mathbf{B} = \mathbf{A}$,

$$\text{then } \mathbf{A}^2 = a_1^2 + a_2^2 + a_3^2 = a^2.$$

The square of a vector has no axis, or, what is probably more correct to say, it has any axis. To find a vector from its square is an entirely indeterminate problem, when the vector is in space. If the vector is restricted to one straight line, there still is an ambiguity of forwards or backwards. Hence the double sign for the square root. Again, since the square of any vector is positive, a negative scalar cannot be the square of a vector. In the algebra of vectors the square root of a negative scalar is not only imaginary, it is impossible.

Reciprocal of a vector.—By the reciprocal of a vector is meant the vector which combined as a factor with the original vector produces the product $+1$. Since

$$\mathbf{AB} = ab\ (\cos\alpha\beta + \sin\alpha\beta \cdot \overline{\alpha\beta})$$

in order that the product may be 1, b must equal a^{-1} and β be identical with α. Thus, $\mathbf{A}^{-1} = a^{-1}\alpha$. It follows that

$$\mathbf{A}^{-1} = \frac{a\alpha}{a^2} = \frac{\mathbf{A}}{\mathbf{A}^2} = \frac{a_1i + a_2j + a_3k}{a_1^2 + a_2^2 + a_3^2};$$

and that $\mathbf{A}^{-1}\mathbf{B} = \dfrac{b}{a}\ (\cos\alpha\beta + \sin\alpha\beta \cdot \overline{\alpha\beta})$.

The expression inside the parenthesis depending on the axes is the same for $\mathbf{AB}$, $\mathbf{A}^{-1}\mathbf{B}$, $\mathbf{AB}^{-1}$, $\mathbf{A}^{-1}\mathbf{B}^{-1}$.

In quaternions the reciprocal of a vector has the opposite axis to that of the vector, but this arises from treating a vector as a quadrantal versor. The reciprocal, as above defined, corresponds to the inverse of a line in geometry, when the constant quantity is 1. Curvature, denoted by $\frac{d^2\mathbf{R}}{ds^2}$, is a directed quantity; its reciprocal, denoted by $\left(\frac{d^2\mathbf{R}}{ds^2}\right)^{-1}$, is the radius of curvature; they have the same axis, but reciprocal magnitudes.

The reciprocal, as above defined, is a true generalization of the reciprocal of algebra; the axis being no longer constant is expressed by α.

It explains why the rule of signs for a quotient is the same as the rule of signs for a product. For example, $\frac{a}{-b} = \frac{-a}{b}$, which means that it is immaterial to the result whether the minus sign occurs in the numerator or the denominator. This view of the generalized reciprocal also explains the change of signs of the trigonometrical functions in the several quadrants.

Generalized trigonometrical functions.—The other trigonometrical functions may be defined in terms of the generalized cosine and sine. Thus,

$$Tan\,\mathbf{AB} = \frac{Sin\,\mathbf{AB}}{cos\,\mathbf{AB}} = \frac{(a_2b_3 - a_3b_2)i + (a_3b_1 - a_1b_3)j + (a_1b_2 - a_2b_1)k}{a_1b_1 + a_2b_2 + a_3b_3}$$

$$Cot\,\mathbf{AB} = \frac{cos\,\mathbf{AB}}{Sin\,\mathbf{AB}} = \frac{cos\,\mathbf{AB}\,Sin\,\mathbf{AB}}{sin^2\,\mathbf{AB}}$$

$$sec\,\mathbf{AB} = \frac{1}{cos\,\mathbf{AB}} = \frac{1}{a_1b_1 + a_2b_2 + a_3b_3}$$

$$Cosec\,\mathbf{AB} = \frac{1}{Sin\,\mathbf{AB}} = \frac{Sin\,\mathbf{AB}}{sin^2\,\mathbf{AB}}$$

While *Tan* **AB** denotes both the magnitude and the axis, *tan* **AB** may be used to denote the magnitude apart from the axis. Whatever the dimensions of **A** and of **B**, *Tan* **AB** has its simple trigonometrical meaning, only it has an axis in space. For

$$Tan\,\mathbf{AB} = \frac{ab\,Sin\,a\beta}{ab\,cos\,a\beta} = Tan\,a\beta.$$

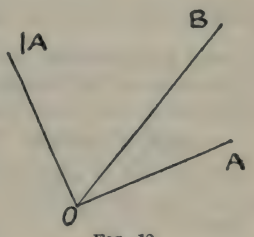

FIG. 12.

Complementary vector.—By the complementary vector (fig. 12) of **A** with respect to **B**, Grassmann means the vector which has the same magnitude as **A** and is drawn perpendicular to **A** in the plane of **A** and **B**.

Thus $|\,\mathbf{A} = a \cdot \overline{\overline{a\beta}a}$

The product $\mathbf{B}\,|\,\mathbf{A} = cos\,\mathbf{B}\,|\,\mathbf{A} + Sin\,\mathbf{B}\,|\,\mathbf{A}$

$$= sin\,\mathbf{AB} + Cos\,\mathbf{AB}$$

where $sin\,\mathbf{AB} = \sqrt{(a_2b_3 - a_3b_2)^2 + (a_3b_1 - a_1b_3)^2 + (a_1b_2 - a_2b_1)^2}$

and $Cos\,\mathbf{AB} = (a_1b_1 + a_2b_2 + a_3b_3)\,\overline{a\beta}$.

PRODUCT OF THREE VECTORS.

Different forms of the product.—Let $\mathbf{A} = a_1i + a_2j + a_3k$, $\mathbf{B} = b_1i + b_2j + b_3k$, and $\mathbf{C} = c_1i + c_2j + c_3k$ denote any three vectors, not necessarily of the same kind; by their product is meant the product

of the product of **A** and **B** with **C**, according to the rules for vectors.

Thus

$$\mathbf{ABC} = (a_1b_1 + a_2b_2 + a_3b_3)\ (c_1i + c_2j + c_3k)$$
$$+ \left\{ (a_2b_3 - a_3b_2)i + (a_3b_1 - a_1b_3)j + (a_1b_2 - a_2b_1)k \right\} (c_1i + c_2j + c_3k)$$
$$= (a_1b_1 + a_2b_2 + a_3b_3)\ (c_1i + c_2j + c_3k) + \begin{vmatrix} \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} & \begin{vmatrix} a_3 & a_1 \\ b_3 & b_1 \end{vmatrix} & \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \\ c_1 & c_2 & c_3 \\ i & j & k \end{vmatrix}$$
$$+ \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}$$

The second term may be written

$$\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \begin{vmatrix} c_1 & c_2 \\ i & j \end{vmatrix} + \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} \begin{vmatrix} c_2 & c_3 \\ j & k \end{vmatrix} + \begin{vmatrix} a_3 & a_1 \\ b_3 & b_1 \end{vmatrix} \begin{vmatrix} c_3 & c_1 \\ k & i \end{vmatrix}$$

If we write $\mathbf{A} = aa$, $\mathbf{B} = b\beta$, $\mathbf{C} = c\gamma$, then

$$\mathbf{ABC} = abc\ (\cos a\beta + \sin a\beta \cdot \overline{a\beta})\ \gamma$$
$$= abc\ \left\{ \cos a\beta \cdot \gamma + \sin a\beta \sin \overline{a\beta}\gamma \cdot \overline{\overline{a\beta}\gamma} + \sin a\beta \cos \overline{a\beta}\gamma \right\}$$

where $\cos \overline{a\beta}\gamma$ denotes the *cosine* between the axis $\overline{a\beta}$ and γ, and $\overline{\overline{a\beta}\gamma}$ denotes the axis perpendicular to $\overline{a\beta}$ and γ.

The parts of the product may be expressed more synthetically by means of the generalized cosine and Sine. Thus

$$\mathbf{ABC} = \cos \mathbf{AB} \cdot \mathbf{C} + \mathit{Sin}\ (\mathit{Sin}\ \mathbf{AB})\mathbf{C} + \cos\ (\mathit{Sin}\ \mathbf{AB})\ \mathbf{C};$$

where the dot is used as a separatrix, to separate the expression for the cosine from the vector.

Thus,

$$\cos \mathbf{AB} \cdot \mathbf{C} = abc \cos a\beta \cdot \gamma = a_1b_1 + a_2b_2 + a_3b_3;$$

$$\mathit{Sin}\ (\mathit{Sin}\ \mathbf{AB})\ \mathbf{C} = abc \sin a\beta \sin \overline{a\beta}\gamma \cdot \overline{\overline{a\beta}\gamma}$$
$$= \begin{vmatrix} a_2b_3 - a_3b_2 & a_3b_1 - a_1b_3 & a_1b_2 - a_2b_1 \\ c_1 & c_2 & c_3 \\ i & j & k \end{vmatrix}$$

and $\cos\ (\mathit{Sin}\ \mathbf{AB})\ \mathbf{C} = abc \sin a\beta \cos \overline{a\beta}\gamma = \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}$

Axis of the third term.—The first term of the product has the axis γ, and the second term the axis perpendicular to $\overline{a\beta}$ and γ; the question arises whether the axis of the third term is implicitly given as the third mutual perpendicular, namely, $\overline{\overline{\gamma\ a\beta}\gamma}$. It can be shown that it is not so; the term is a scalar for space of three dimensions, but has an axis in space

of four dimensions. If the vectors **A**, **B**, **C** are each of one dimension in length, each of the terms of the product is of three dimensions in length. The third term involves the three axes of space symmetrically, hence has no axes. It is a scalar, but not of the same kind as *cos* **AB**. This view of the term becomes clearer, when the product of three line-vectors in space of four dimensions is considered.

To express the second term as the difference of two terms similar to the first.—The second term *Sin* (*Sin* **AB**) **C** expressed in terms of i, j, k is

$$\left\{-(b_2c_2 + b_3c_3)\,a_1 + (c_2a_2 + c_3a_3)\,b_1\right\}i$$
$$+\left\{-(b_3c_3 + b_1c_1)\,a_2 + (c_3a_3 + c_1a_1)\,b_2\right\}j$$
$$+\left\{-(b_1c_1 + b_2c_2)\,a_3 + (c_1a_1 + c_2a_2)\,b_3\right\}k$$

By adding the null term $(b_1c_1a_1 - c_1a_1b_1)\,i$ to the i term, we get

$$-\cos \mathbf{BC}\,a_1i + \cos \mathbf{CA}\,b_1i.$$

By treating similarly the other two components and adding the results, we obtain

$$Sin\,(Sin\,\mathbf{AB})\,\mathbf{C} = -\cos \mathbf{BC}\cdot\mathbf{A} + \cos \mathbf{CA}\cdot\mathbf{B}.$$

Hence,

$$\mathbf{ABC} = \cos \mathbf{AB}\cdot\mathbf{C} - \cos \mathbf{BC}\cdot\mathbf{A} + \cos \mathbf{CA}\cdot\mathbf{B} + \cos\,(Sin\,\mathbf{AB})\,\mathbf{C}.$$

The vector which is the sum of all the vector terms may be called the total vector.

The product of three vectors is not indifferent as regards association.—The expression **ABC**, without any parenthesis, means that the association of the factors begins at the left, while **A**(**BC**) denotes that the association begins at the right. By applying the rules of multiplication we get

$$\mathbf{A}(\mathbf{BC}) = \mathbf{A}\cos \mathbf{BC} + Sin\,\mathbf{A}\,(Sin\,\mathbf{BC}) + \cos \mathbf{A}\,(Sin\,\mathbf{BC}).$$

On comparing these terms with those of **ABC**, it will be seen, by a well-known property of the determinant, that the third terms are equal. But

$$Sin\,\mathbf{A}\,(Sin\,\mathbf{BC}) = -\,Sin\,(Sin\,\mathbf{BC})\,\mathbf{A} = \cos \mathbf{CA}\cdot\mathbf{B} - \cos \mathbf{AB}\cdot\mathbf{C};$$

Hence the total vector of **A**(**BC**) is

$$\cos \mathbf{BC}\cdot\mathbf{A} + \cos \mathbf{CA}\cdot\mathbf{B} - \cos \mathbf{AB}\cdot\mathbf{C},$$

which is equal in magnitude to the total vector of **ABC**, but does not have the same direction. The condition which must obtain for the rule of association to be applied is

$$\cos \mathbf{AB}\cdot\mathbf{C} = \cos \mathbf{BC}\cdot\mathbf{A},$$

that is, **C** and **A** must have the same direction.

When the three vectors are coplanar, the middle vector and the non-associated vector may be interchanged.—For then

$$(\mathbf{AB})\mathbf{C} = \cos \mathbf{AB}\cdot\mathbf{C} - \cos \mathbf{BC}\cdot\mathbf{A} + \cos \mathbf{CA}\cdot\mathbf{B},$$

and

$$(\mathbf{AC})\mathbf{B} = \cos \mathbf{AC}\cdot\mathbf{B} - \cos \mathbf{CB}\cdot\mathbf{A} + \cos \mathbf{BA}\cdot\mathbf{C}.$$

Hence,

$$\mathbf{A}^3 = a^2\mathbf{A} = \mathbf{A}a^2;$$
$$(\mathbf{AB})\mathbf{A} = (\mathbf{AA})\mathbf{B} = a^2\mathbf{B};$$
$$(\mathbf{AB})\mathbf{A}^{-1} = (\mathbf{AA}^{-1})\mathbf{B} = \mathbf{B}.$$

But $(\mathbf{BA})\mathbf{A}^{-1} = (\mathbf{BA}^{-1})\mathbf{A}$ and is not $= \mathbf{B}$.

It is evident (fig. 13) that $\mathbf{BAA^{-1}}$ is the vector which is the reflection of **B** in **A**.

Cyclical products.—The three products of **A**, **B**, **C** obtained by taking the factors in cyclical order, and so changing the mode of association are,

$$\mathbf{ABC} = cos\,\mathbf{AB}\cdot\mathbf{C} + \left\{ - cos\,\mathbf{BC}\cdot\mathbf{A} + cos\,\mathbf{CA}\cdot\mathbf{B} \right\} + cos\,(Sin\,\mathbf{AB})\,\mathbf{C},$$

$$\mathbf{BCA} = cos\,\mathbf{BC}\cdot\mathbf{A} + \left\{ - cos\,\mathbf{CA}\cdot\mathbf{B} + cos\,\mathbf{AB}\cdot\mathbf{C} \right\} + cos\,(Sin\,\mathbf{BC})\,\mathbf{A},$$

$$\mathbf{CAB} = cos\,\mathbf{CA}\cdot\mathbf{B} + \left\{ - cos\,\mathbf{AB}\cdot\mathbf{C} + cos\,\mathbf{BC}\cdot\mathbf{A} \right\} + cos\,(Sin\,\mathbf{CA})\,\mathbf{B}.$$

The last term has the same value in the three products; it expresses the volume of the parallelopiped formed by the three vectors and may be denoted by *vol* **ABC**. The sum of the three products is

$$\mathbf{ABC} + \mathbf{BCA} + \mathbf{CAB} = cos\,\mathbf{AB}\cdot\mathbf{C} + cos\,\mathbf{BC}\cdot\mathbf{A} + cos\,\mathbf{CA}\cdot\mathbf{B} + 3\,vol\,\mathbf{ABC}.$$

By abstracting the common magnitude *abc* of the total vectors, the following ratio-vectors are obtained:

$$cos\,\alpha\beta\cdot\gamma - cos\,\beta\gamma\cdot\alpha + cos\,\gamma\alpha\cdot\beta \qquad (1)$$

$$cos\,\beta\gamma\cdot\alpha - cos\,\gamma\alpha\cdot\beta + cos\,\alpha\beta\cdot\gamma \qquad (2)$$

$$cos\,\gamma\alpha\cdot\beta - cos\,\alpha\beta\cdot\gamma + cos\,\beta\gamma\cdot\alpha \qquad (3)$$

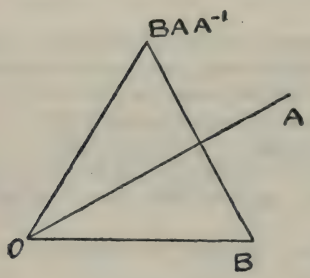

FIG. 13.

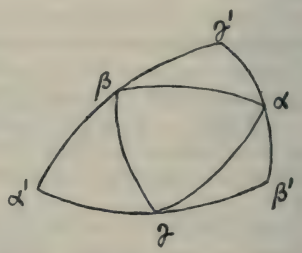

FIG. 14.

In quaternions these expressions are obtained from $\beta\alpha^{-1}\gamma$, $\gamma\beta^{-1}\alpha$, $\alpha\gamma^{-1}\beta$, but here we are led to them directly by varying the product so as to get the three modes of association. Let α, β, γ (fig. 14) be the extremities of the axes on the unit-sphere. As the vector (1) has a negative component along α, it will be on the opposite side of the arc $\beta\gamma$ from α; let α' be its axis. Similarly β' denotes the axis of (2) and γ' that of (3).

Since (1) + (2) = 2 $cos\,\alpha\beta\cdot\gamma$ and (2) + (3) = 2 $cos\,\beta\gamma\cdot\alpha$ and (3) + (1) = 2 $cos\,\gamma\alpha\cdot\beta$; the axes α', β', γ' are such that the triangle $\alpha'\beta'\gamma'$ has its sides bisected by the triangle $\alpha\beta\gamma$.

Notation.—The square of each of the vectors (1), (2), (3) is

$$cos^2\alpha\beta + cos^2\beta\gamma + cos^2\gamma\alpha - 2cos\,\alpha\beta\,cos\,\beta\gamma\,cos\,\gamma\alpha,$$

which is the complement to one of $vol^2\ a\beta\gamma$. In spherical trigonometry $vol\ a\beta\gamma$ is denoted by $2n$, which is equal to

$$2\left\{\sin s \sin(s-a)\sin(s-b)\sin(s-c)\right\}^{\frac{1}{2}}$$

and the need of a name for the function has been felt. It has been called by some the "sine of the trihedral angle" formed by α, β, γ; by others the "Staudtian" (Casey, *Spherical Trigonometry*, p. 22). The notation $(a\beta\gamma)$ is used by Lagrange in the *Mecanique Analytique;* in quaternions it is denoted by $-Sa\beta\gamma$ and the total vector by $Va\beta\gamma$.

PRODUCT OF FOUR VECTORS.

Different ways of association.—A product of four vectors may be formed in five different ways, according to the nature of the association, namely, ((**AB**) **C**) **D**, (**A** (**BC**)) **D**, **A** ((**BC**) **D**), **A** (**B** (**CD**)), (**AB**) (**CD**), of which the first and last are the most important. When no parenthesis is used, the first form is understood.

The first form of the product.—Let **A**, **B** and **C** be expressed as before in terms of i, j, k and let $\mathbf{D} = d_1 i + d_2 j + d_3 k$. Then

$$\mathbf{ABCD} = (a_1b_1 + a_2b_2 + a_3b_3)(c_1d_1 + c_2d_2 + c_3d_3) \quad (1)$$

$$+ \begin{vmatrix} \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} & \begin{vmatrix} a_3 & a_1 \\ b_3 & b_1 \end{vmatrix} & \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \\ c_1 & c_2 & c_3 \\ d_1 & d_2 & d_3 \end{vmatrix} \quad (2)$$

$$+ (a_1b_1 + a_2b_2 + a_3b_3) \begin{vmatrix} c_1 & c_2 & c_3 \\ d_1 & d_2 & d_3 \\ i & j & k \end{vmatrix} \quad (3)$$

$$+ \begin{vmatrix} \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} & \begin{vmatrix} a_3 & a_1 \\ b_3 & b_1 \end{vmatrix} & \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \\ c_1 & c_2 & c_3 \\ \begin{vmatrix} d_2 & d_3 \\ j & k \end{vmatrix} & \begin{vmatrix} d_3 & d_1 \\ k & i \end{vmatrix} & \begin{vmatrix} d_1 & d_2 \\ i & j \end{vmatrix} \end{vmatrix} \quad (4)$$

$$+ \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} (d_1 i + d_2 j + d_3 k) \quad (5)$$

The term (2) is equal to

$$-(b_1c_1 + b_2c_2 + b_3c_3)(a_1d_1 + a_2d_2 + a_3d_3)$$
$$+ (c_1a_1 + c_2a_2 + c_3a_3)(b_1d_1 + b_2d_2 + b_3d_3),$$

and the term (4) is equal to

$$-(b_1c_1 + b_2c_2 + b_3c_3) \begin{vmatrix} a_1 & a_2 & a_3 \\ d_1 & d_2 & d_3 \\ i & j & k \end{vmatrix} + (c_1a_1 + c_2a_2 + c_3a_3) \begin{vmatrix} b_1 & b_2 & b_3 \\ d_1 & d_2 & d_3 \\ i & j & k \end{vmatrix}.$$

Let $\mathbf{A} = a\alpha$, $\mathbf{B} = b\beta$, $\mathbf{C} = c\gamma$, $\mathbf{D} = d\delta$; then

$$\mathbf{ABCD} = abcd\Big\{\cos\alpha\beta\cos\gamma\delta + \sin\alpha\beta\sin\overline{\alpha\beta}\,\gamma\cos\overline{\overline{\alpha\beta}\,\gamma}\,\delta$$
$$+ \cos\alpha\beta\sin\gamma\delta\cdot\overline{\gamma\delta} + \sin\alpha\beta\sin\overline{\alpha\beta}\,\gamma\sin\overline{\overline{\alpha\beta}\,\gamma}\,\delta\cdot\overline{\overline{\overline{\alpha\beta}\,\gamma}\,\delta}$$
$$+ \sin\alpha\beta\cos\overline{\alpha\beta}\,\gamma\cdot\delta\Big\}.$$

These five terms are equal in order to (1), (2), (3), (4), (5) respectively. By expanding the second and fourth terms,

$$\mathbf{ABCD} = abcd\Big\{ \cos\alpha\beta\cos\gamma\delta - \cos\beta\gamma\cos\alpha\delta + \cos\gamma\alpha\cos\beta\delta$$
$$+ \cos\alpha\beta\sin\gamma\delta\cdot\overline{\gamma\delta} - \cos\beta\gamma\ \sin\alpha\delta\cdot\overline{\alpha\delta} + \cos\gamma\alpha\ \sin\beta\delta\cdot\overline{\beta\delta}$$
$$+ \sin\alpha\beta\cos\overline{\alpha\beta}\gamma\cdot\delta\Big\}.$$

The product may be expressed more synthetically by

$$\mathbf{ABCD} = \cos\mathbf{AB}\cos\mathbf{CD} + \cos(Sin\ (Sin\,\mathbf{AB})\ \mathbf{C})\ \mathbf{D} + \cos\mathbf{AB}\ Sin\mathbf{CD}$$
$$+ Sin\Big\{ Sin\ (Sin\mathbf{AB})\ \mathbf{C}\Big\}\mathbf{D} + \cos\ (Sin\mathbf{AB})\ \mathbf{C}\cdot\mathbf{D}.$$

The symmetrical product. — By the symmetrical product is meant $(\mathbf{AB})\ (\mathbf{CD})$.

Since $\mathbf{AB} = ab\ (\cos\alpha\beta + \sin\alpha\beta\cdot\overline{\alpha\beta})$

and $\mathbf{CD} = cd\ (\cos\gamma\delta + \sin\gamma\delta\cdot\overline{\gamma\delta})$

$$(\mathbf{AB})\ (\mathbf{CD}) = abcd\Big\{ \cos\alpha\beta\cos\gamma\delta + \cos\alpha\beta\sin\gamma\delta\cdot\overline{\gamma\delta} + \cos\gamma\delta\sin\alpha\beta\cdot\overline{\alpha\beta}$$
$$+ \sin\alpha\beta\sin\gamma\delta\cos\overline{\alpha\beta}\ \overline{\gamma\delta} + \sin\alpha\beta\sin\gamma\delta\sin\overline{\alpha\beta}\ \overline{\gamma\delta}\cdot\overline{\overline{\alpha\beta}\ \overline{\gamma\delta}}\Big\}$$

This differs essentially from the product of two quaternions, for in it the last two terms are negative. How then can it satisfy the law of the norms? By considering the five terms to be independent of one another.

COMPOUND AXES.

By an axis of the *first degree* is meant the direction of a line; it is denoted by an elementary symbol such as α.

By an axis of the *second degree* is meant the product of two elementary axes, denoted in general by $\alpha\beta$.

Now,

$$\alpha\beta = \cos\alpha\beta + \sin\alpha\beta\cdot\overline{\alpha\beta};$$

hence, $\alpha^2 = +$ and when β is perpendicular to α, the axis reduces to $\overline{\alpha\beta}$. Also $\overline{\beta\alpha} = -\overline{\alpha\beta}$.

By an axis of the *third degree* is meant the product of three elementary axes, denoted in general by $\alpha\beta\gamma$. We have seen that

$$\alpha\beta\gamma = \cos\alpha\beta\cdot\gamma - \cos\beta\gamma\cdot\alpha + \cos\gamma\alpha\cdot\beta + \sin\alpha\beta\cos\overline{\alpha\beta}\gamma\cdot\overline{\alpha\beta\gamma},$$

where $\overline{\alpha\beta\gamma}$ denotes the axis of the third term.

Let $\gamma = \alpha$; then the axis reduces to $\alpha\beta\alpha$, that is β.

Let $\gamma = \beta$; then the axis reduces to $\alpha\beta\beta$, which is equal to

$$2\cos\alpha\beta\cdot\beta - \alpha.$$

Hence, if α and β are at right angles, $\alpha\beta\beta$ reduces to $-\alpha$.

If α, β and γ are mutually rectangular, the general axis $\alpha\beta\gamma$ reduces to $\overline{\alpha\beta\gamma}$, which therefore is an axis in a space of four dimensions. In such a space, volume has an axis. It is such that

$$\overline{\alpha\beta\gamma} = \overline{\beta\gamma\alpha} = \overline{\gamma\alpha\beta} = -\overline{\gamma\beta\alpha} = -\overline{\beta\alpha\gamma} = -\overline{\alpha\gamma\beta}.$$

The rule of signs for a determinant of the third order is the rule for the direction along this axis. In a space of three dimensions when α, β, γ are mutually rectangular $\overline{\alpha\beta\gamma}$ is the only extraspatial axis, and may be denoted in a certain sense by 1; and $\overline{\alpha\beta}$ is equivalent to the complementary axis γ. Thus, $ij = k$ introduces the condition of three dimensions.

By an axis of the *fourth degree* is meant the product of four elementary axes; it is denoted in general by $\alpha\beta\gamma\delta$, and we have shown that

$$\alpha\beta\gamma\delta = \cos\alpha\beta\cos\gamma\delta - \cos\beta\gamma\cos\alpha\delta + \cos\gamma\alpha\cos\beta\delta$$
$$+ \cos\alpha\beta\sin\gamma\delta\cdot\overline{\gamma\delta} - \cos\beta\gamma\cos\alpha\delta\cdot\overline{\alpha\delta} + \cos\gamma\alpha\sin\beta\delta\cdot\overline{\beta\delta}$$
$$+ \sin\alpha\beta\cos\overline{\alpha\beta\gamma}\cdot\overline{\alpha\beta\gamma}\,\delta.$$

If α, β and γ are mutually rectangular, the axis reduces to $\overline{\alpha\beta\gamma}\,\delta$. If $\delta = \alpha$, the axis has the same direction as $\overline{\beta\gamma}$, but the sign remains to be determined. As in space of three dimensions $\overline{\beta\gamma} = \alpha$ and $\overline{\alpha\beta\gamma} = 1$, the sign is $+$. Hence, $\alpha\beta\gamma\,\alpha = \overline{\beta\gamma}$ in general. Let $\delta = \beta$; then since $\overline{\alpha\beta\gamma} = -\overline{\beta\alpha\gamma}$, it follows that $\overline{\alpha\beta\gamma}\,\beta = -\overline{\alpha\gamma}$. Similarly, $\overline{\alpha\beta\gamma}\,\gamma = \alpha\beta$.

If, in addition δ is at right angles to α, β and γ, we have a new axis $\overline{\alpha\beta\gamma\delta}$, which is transformed according to the rules for a determinant of the fourth order, namely, $\overline{\alpha\beta\delta\gamma} = -\overline{\beta\gamma\delta\alpha} = \overline{\gamma\delta\alpha\beta} = -\overline{\delta\alpha\beta\gamma}$, etc.

The following table contains the different types of axes for the first four degrees, with their reduced equivalents. It is supposed that i, j, k, u are mutually rectangular.

DEGREE.	TYPE.	GENERAL REDUCED AXIS.	REDUCED AXIS IN SPACE OF THREE DIMENSIONS.
First.	i		
Second.	i^2	$+$	$+$
	ij		k
Third.	i^3	i	i
	i^2j	j	j
	iji	j	j
	ijj	$-i$	$-i$
	ijk		$+$
Fourth.	i^4	$+$	$+$
	i^3j	ij	k
	i^2ji	$-ij$	$-k$
	i^2jj	$+$	$+$

DEGREE.	TYPE.	GENERAL REDUCED AXIS.	REDUCED AXIS IN SPACE OF THREE DIMENSIONS.
Fourth.	i^2jk	jk	i
	$ijii$	$-ij$	$-k$
	$ijij$	$+$	$+$
	$ijik$	jk	i
	$ijji$	$-$	$-$
	$ijjj$	$-ij$	$-k$
	$ijjk$	$-ik$	j
	$ijki$	jk	i
	$ijkj$	$-ik$	j
	$ijkk$	ij	k
	$ijku$		Non-existent.

These principles suffice to reduce an axis of any degree.

General product of two vectors.—Let

$$\mathbf{R} = xa + y\beta + z\gamma + w\delta + \text{etc.}$$
$$\mathbf{R}' = x'a + y'\beta + z'\gamma + w'\delta + \text{etc.};$$

then

$$\mathbf{RR}' = \Sigma xx' + \Sigma\,(xy' + yx')\cos\alpha\beta + \Sigma\,(xy' - yx')\sin\alpha\beta\cdot\overline{\alpha\beta}.$$

Thus,

$$\cos\mathbf{RR}' = \Sigma xx' + \Sigma(xy' + yx')\cos\alpha\beta$$

and

$$Sin\,\mathbf{RR}' = \Sigma(xy' - yx')\sin\alpha\beta\cdot\overline{\alpha\beta}.$$

In a space of four dimensions a, β, γ, δ may be independent; and $\frac{\cos\mathbf{RR}'}{rr'}$ expresses the cosine of the angle between the vectors, and $\frac{Sin\,\mathbf{RR}'}{rr'}$ expresses the directed sine. In a space of three dimensions, these expressions still have the same meaning, although only three of the axes can be independent. In a space of two dimensions the component areas all have the same direction but may differ in sign. For three components,

$$Sin\,\mathbf{RR}' = \begin{vmatrix} x & y & z \\ x' & y' & z' \\ \sin\beta\gamma & \sin\gamma\alpha & \sin\alpha\beta \end{vmatrix}$$

where the sines are algebraic quantities, that is, have a common direction but may be positive or negative. In a space of one dimension

$$\mathbf{RR}' = \Sigma xx' + \Sigma(xy' + yx')$$

which agrees with ordinary algebra. Whatever the space,

$$\mathbf{R}^2 = \Sigma x^2 + 2\Sigma xy\cos\alpha\beta.$$

Product of three vectors in space of four dimensions.—Let

$$\mathbf{A} = a_1 i + a_2 j + a_3 k + a_4 u$$
$$\mathbf{B} = b_1 i + b_2 j + b_3 k + b_4 u$$
$$\mathbf{C} = c_1 i + c_2 j + c_3 k + c_4 u.$$

Then $\mathbf{ABC} = \Sigma i^3 + \Sigma i^2 j + \Sigma iji + \Sigma ijj + \Sigma ijk.$

$$\Sigma i^3 = a_1 b_1 c_1 i + a_2 b_2 c_2 j + a_3 b_3 c_3 k + a_4 b_4 c_4 u.$$

$$\Sigma i^2 j = (a_2 b_2 + a_3 b_3 + a_4 b_4)\, c_1 i + (a_3 b_3 + a_4 b_4 + a_1 b_1)\, c_2 j.$$
$$+ (a_4 b_4 + a_1 b_1 + a_2 b_2)\, c_3 k + (a_1 b_1 + a_2 b_2 + a_3 b_3)\, c_4 u.$$

$$\Sigma iji = (a_2 c_2 + a_3 c_3 + a_4 c_4)\, b_1 i + (a_3 c_3 + a_4 c_4 + a_1 c_1)\, b_2 j$$
$$+ (a_4 c_4 + a_1 c_1 + a_2 c_2)\, b_3 k + (a_1 c_1 + a_2 c_2 + a_3 c_3)\, b_4 u.$$

$$\Sigma ijj = -(b_2 c_2 + b_3 c_3 + b_4 c_4)\, a_1 i - (b_3 c_3 + b_4 c_4 + b_1 c_1)\, a_2 j$$
$$- (b_4 c_4 + b_1 c_1 + b_2 c_2)\, a_3 k - (b_1 c_1 + b_2 c_2 + b_3 c_3)\, a_4 u.$$

$$\Sigma ijk = \begin{vmatrix} a_1 & a_2 & a^3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} ijk + \begin{vmatrix} a_2 a_3 & a_4 \\ b_2 & b_3 & b_4 \\ c_2 & c_3 & c_4 \end{vmatrix} jku + \begin{vmatrix} a_3 & a_4 & a_1 \\ b_3 & b_4 & b_1 \\ c_3 & c_4 & c_1 \end{vmatrix} kui + \begin{vmatrix} a_4 & a_1 & a_2 \\ b_4 & b_1 & b_2 \\ c_4 & c_1 & c_2 \end{vmatrix} uij$$

$$= \begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ jku & kui & uij & ijk \end{vmatrix} = \begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ -i & j & -k & u \end{vmatrix}.$$

Thus, in a space of three dimensions $\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}$ is a true imaginary; its axis being the fourth axis in a space of four dimensions.

Product of four vectors in space of four dimensions.—By means of the types, given above, the complete product may be formed. In space of three dimensions all the types exist excepting the last. It has commonly been supposed that the product of four lines is impossible. For instance, De Morgan (Double Algebra, p. 107) says that *ABCD* is unintelligible, space not having four dimensions; and Gregory, in his paper on the "Application of Algebraical Symbols to Geometry," says, "If we combine more symbols than three, we find no geometrical interpretation for the result. In fact, it may be looked on as an impossible geometrical operation; just as $\sqrt{-1}$ is an impossible arithmetical one."

QUATERNIONS.

Definition.—By a quaternion proper is meant an arithmetical ratio combined with an amount of turning. It contains three elements: a ratio, an axis and an amount of angle. Let $\mathbf{a}$ denote a quaternion, a its ratio, α its axis and A the amount of angle; then $\mathbf{a} = a\alpha^A$. It is called a quaternion, because α requires two numbers to specify it, while a and A each requires one; in all, four numbers. The ratio of two vectors is a more determinate quantity; it may involve a physical ratio, and the angle is fixed (fig. 15). If $\mathbf{A}$ and $\mathbf{B}$ are line-vectors, they define a quaternion, provided they are free to rotate round the axis $\overline{\alpha\beta}$.

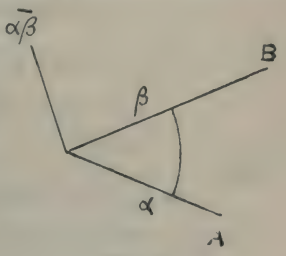

FIG. 15.

Components of a quaternion. — A quaternion may be expressed as the sum of two components, one of which has an indefinite axis, and the other the same axis as the quaternion. Consider the quaternion $a\alpha^A$. If A is less than a quadrant

$$a\alpha^A = a\,(cos\,A \cdot \alpha^0 + sin\,A \cdot \alpha^{\frac{\pi}{2}})$$

If A is between one and two quadrants

$$a\alpha^A = a\,(cos\,A \cdot \alpha^{\pi} + sin\,A \cdot \alpha^{\frac{\pi}{2}})$$

If A is between two and three quadrants

$$a\alpha^A = a\,(cos\,A \cdot \alpha^{\pi} + sin\,A \cdot \alpha^{\frac{3\pi}{2}})$$

If A is between three and four quadrants

$$a\alpha^A = a\,(cos\,A \cdot \alpha^{2\pi} + sin\,A \cdot \alpha^{\frac{3\pi}{2}})$$

and so on, for any amount of angle. Here *cos A* and *sin A* are looked upon as signless ratios. If the number of half revolutions is thrown into the ratios *cos A* and *sin A*, making them algebraic ratios, then, when A is less than a revolution

$$a\alpha^A = a\,(cos\,A + sin\,A \cdot \alpha^{\frac{\pi}{2}})$$

and generally $a\alpha^{2r\pi+A} = a\alpha^{2r\pi}\,(cos\,A + sin\,A \cdot \alpha^{\frac{\pi}{2}})$

When the quaternions are all in one plane, α is constant, and need not be expressed. The quaternion takes the form of the complex ratio

$$a \cdot A = a\,(cos\,A + sin\,A \cdot \tfrac{\pi}{2})$$

the angle $\frac{\pi}{2}$ being expressed by $\sqrt{-1}$.

If further, the quaternions are restricted to one line, the angle A can only be 0 or π; and $a \cdot 0 = a$, $a \cdot \pi = -a$.

The above equations are homogeneous; a quaternion is equated to the sum of two quaternions, the only peculiarity being that the axis of one of the components may be any axis.

SUM OF TWO QUATERNIONS.

Let $\mathbf{a} = a\,\alpha^A$ and $\mathbf{b} = b\,\beta^B$ be the two quaternions.

Since

$$\mathbf{a} = a\,(cos\,A + sin\,A \cdot \alpha^{\frac{\pi}{2}}),$$

$$\mathbf{b} = b\,(cos\,B + sin\,B \cdot \beta^{\frac{\pi}{2}}),$$

$$\mathbf{a} + \mathbf{b} = (a\,cos\,A + b\,cos\,B) + (a\,sin\,A \cdot \alpha^{\frac{\pi}{2}} + b\,sin\,B \cdot \beta^{\frac{\pi}{2}})$$

$$= (a\,cos\,A + b\,cos\,B) + (a\,sin\,A \cdot \alpha + b\,sin\,B \cdot \beta)^{\frac{\pi}{2}}$$

$$= r\,\varphi^{\theta}$$

where

$$r = \sqrt{a^2 + b^2 + 2ab\,(cos\,A\ cos\,B + sin\,A\ sin\,B\ cos\,\alpha\beta)}$$

$$\varphi = \frac{a\,sin\,A \cdot \alpha + b\,sin\,B \cdot \beta}{r}$$

and $\theta = cos^{-1}\,\frac{a\,cos\,A + b\,cos\,B}{r}$

If $\mathbf{a}$ is given in the form $a_0 + \mathbf{A}^{\frac{\pi}{2}}$ and $\mathbf{b}$ in the form $b_0 + \mathbf{B}^{\frac{\pi}{2}}$; then

$$\mathbf{a} + \mathbf{b} = a_0 + b_0 + (\mathbf{A} + \mathbf{B})^{\frac{\pi}{2}}$$

Here $\mathbf{A}$ and $\mathbf{B}$ denote vectors of zero dimensions.

If
$$\mathbf{a} = a_0 + (a_1 i + a_2 j + a_3 k)^{\frac{\pi}{2}}$$
$$\mathbf{b} = b_0 + (b_1 i + b_2 j + b_3 k)^{\frac{\pi}{2}}$$

then $\mathbf{a} + \mathbf{b} = a_0 + b_0 + \left\{(a_1 + b_1)i + (a_2 + b_2)j + (a_3 + b_3)k\right\}^{\frac{\pi}{2}}$

This is the addition of complex numbers not confined to one plane.

PRODUCT OF TWO QUATERNIONS.

By the product of two quaternions is meant the product of the tensors combined with the sum of the versors. The product is a quantity of the same kind as either factor; it is the generalization for space of the product of ratios.

Let the two quaternions be

$$\mathbf{a} = a_0 + (a_1 i + a_2 j + a_3 k)^{\frac{\pi}{2}}$$
$$\mathbf{b} = b_0 + (b_1 i + b_2 j + b_3 k)^{\frac{\pi}{2}},$$

then by the rules for versors (p. 75)

$$\mathbf{ab} = a_0 b_0 - (a_1 b_1 + a_2 b_2 + a_3 b_3)$$
$$+ \left\{ \begin{array}{l} a_0 (b_1 i + b_2 j + b_3 k) + b_0 (a_1 i + a_2 j + a_3 k) \\ \quad - (a_2 b_3 - a_3 b_2) i - (a_3 b_1 - a_1 b_3) j - (a_1 b_2 - a_2 b_1) k \end{array} \right\}^{\frac{\pi}{2}}$$

Let *cos* $\mathbf{ab}$ denote the cosine of the angle of the product multiplied by the tensors of $\mathbf{a}$ and $\mathbf{b}$, and *Sin* $\mathbf{ab}$ the directed sine of the same angle multiplied in the same manner; then

$$\textit{cos}\ \mathbf{ab} = a_0 b_0 - (a_1 b_1 + a_2 b_2 + a_3 b_3)$$
$$\text{and } \textit{Sin}\ \mathbf{ab} = a_0 (b_1 i + b_2 j + b_3 k) + b_0 (a_1 i + a_2 j + a_3 k) - \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ i & j & k \end{vmatrix}$$

If the factors are expressed more synthetically by

$$\mathbf{a} = a_0 + \mathbf{A}^{\frac{\pi}{2}}, \qquad \mathbf{b} = b_0 + \mathbf{B}^{\frac{\pi}{2}},$$

then $\mathbf{ab} = a_0 b_0 - \textit{cos}\ \mathbf{AB} + (b_0 \mathbf{A} + a_0 \mathbf{B} - \textit{Sin}\ \mathbf{AB})^{\frac{\pi}{2}}$.

Trigonometrical form of the product.—Let

$$\mathbf{a} = a\alpha^A, \qquad \mathbf{b} = b\beta^B;$$

then
$$\mathbf{a} = a\left(\cos A + \sin A \cdot \alpha^{\frac{\pi}{2}}\right),$$
$$\mathbf{b} = b\left(\cos B + \sin B \cdot \beta^{\frac{\pi}{2}}\right);$$

and $\mathbf{ab} = ab\left\{\cos A \cos B - \sin A \sin B \cos \alpha\beta\right\}$

$$+ ab\left\{\cos B \sin A \cdot \alpha + \cos A \sin B \cdot \beta - \sin A \sin B \sin \alpha\beta \cdot \overline{\alpha\beta}\right\}^{\frac{\pi}{2}}$$

Let $a = b = 1$; then (fig. 16)

$$\cos a^A \beta^B = \cos A \cos B - \sin A \sin B \cos a\beta,$$

which is the fundamental proposition in spherical trigonometry; it is the cosine of the sum of the angles. Also

$$Sin\, a^A \beta^B = \cos B \sin A \cdot \alpha + \cos A \sin B \cdot \beta - \sin A \sin B \sin a\beta \cdot \overline{\alpha\beta}$$

is the expression for the directed sine of the same sum.

Let β coincide with α; we get the fundamental propositions of plane trigonometry, namely,

$$\cos a^{A+B} = \cos A \cos B - \sin A \sin B,$$

and

$$Sin\, a^{A+B} = (\cos B \sin A + \cos A \sin B) \cdot \alpha.$$

When only one plane is considered, α may be omitted, and the expressions become

$$\cos (A + B) = \cos A \cos B - \sin A \sin B$$
$$\sin (A + B) = \cos B \sin A + \cos A \sin B.$$

Here we have evidence that the consistent order of the factors in a quaternion is from left to right; for, when particularized for a plane, we get the established order in plane trigonometry.

Let $A = B = \frac{\pi}{2}$;

then $$a a^{\frac{\pi}{2}} b \beta^{\frac{\pi}{2}} = -ab\,(\cos a\beta + \sin a\beta \cdot \overline{\alpha\beta}^{\frac{\pi}{2}})$$

This is the product of two quadrantal quaternions, which in works on quaternions is identified with the product of two vectors, only the sign of the second term is made positive.

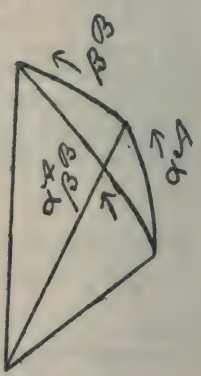

FIG. 16.

Second power of a quaternion.—By the second power of a quaternion is meant the product of the quaternion by itself. From the general product it follows that $a a^A \; a a^A = a^2 a^{2A}$. The ratio is raised to the second power, the axis remains the same, the angle is doubled. This is not a square in the proper sense of the word.

Reciprocal of a quaternion.—The quaternion $\mathbf{b}$ is the reciprocal of $\mathbf{a}$, if $\mathbf{ab} = 1$. Hence its ratio must be the reciprocal of the ratio of a, its axis opposite but its angle equal. Let it be denoted by $\mathbf{a}^{-1}$; then

$$\mathbf{a}^{-1} = \frac{1}{a}\left\{\cos A + \sin A\,(-\alpha)^{\frac{\pi}{2}}\right\}$$

$$= \frac{1}{a}\left\{\cos A - \sin A\, \alpha^{\frac{\pi}{2}}\right\}$$

The reciprocal of the versor α^A is the versor $(-\alpha)^A$ or α^{-A}.

Since $$\alpha^A + \alpha^{-A} = 2 \cos A,$$

and $$\alpha^A - \alpha^{-A} = 2 \sin A \cdot \alpha^{\frac{\pi}{2}};$$

by taking the second power of the former

$$a^{2A} + 2 + a^{-2A} = 4\cos^2 A$$

that is $$\cos 2A + 1 = 2\cos^2 A;$$

and by taking the second power of the latter

$$a^{2A} - 2 + a^{-2A} = -4\sin^2 A.$$

that is $$\cos 2A - 1 = -2\sin^2 A.$$

PRODUCT OF THREE QUATERNIONS.

As the product of two quaternions is a quaternion, the product of that product with a third quaternion is found by the same rules as before.

Let $\mathbf{a} = a_0 + \mathbf{A}^{\frac{\pi}{2}}$, $\mathbf{b} = b_0 + \mathbf{B}^{\frac{\pi}{2}}$, $\mathbf{C} = c_0 + \mathbf{C}^{\frac{\pi}{2}}$.

Now, $\mathbf{ab} = a_0 b_0 - \cos \mathbf{AB} + (b_0 \mathbf{A} + a_0 \mathbf{B} - \mathit{Sin}\, \mathbf{AB})^{\frac{\pi}{2}}$;
and by taking the several products of these terms with those of $\mathbf{c}$, we obtain

$$\mathbf{abc} = a_0 b_0 c_0 - a_0 \cos \mathbf{BC} - b_0 \cos \mathbf{AC} - c_0 \cos \mathbf{AB} + \cos\,(\mathit{Sin}\, \mathbf{AB})\, \mathbf{C}$$

$$+ \left\{ \begin{array}{l} b_0 c_0 \mathbf{A} + c_0 a_0 \mathbf{B} + a_0 b_0 \mathbf{C} - \cos \mathbf{AB} \cdot \mathbf{C} - a_0 \mathit{Sin}\, \mathbf{BC} \\ \quad - b_0 \mathit{Sin}\, \mathbf{AC} - c_0 \mathit{Sin}\, \mathbf{AB} + \mathit{Sin}\,(\mathit{Sin}\, \mathbf{AB})\, \mathbf{C} \end{array} \right\}^{\frac{\pi}{2}}$$

As this is itself a quaternion, the former term may be denoted by $\cos \mathbf{abc}$, and the latter by $\mathit{Sin}\, \mathbf{abc}$. The latter may be written in the more symmetrical form

$$b_0 c_0 \mathbf{A} + c_0 a_0 \mathbf{B} + a_0 b_0 \mathbf{C} - \cos \mathbf{BC} \cdot \mathbf{A} + \cos \mathbf{CA} \cdot \mathbf{B} - \cos \mathbf{AB} \cdot \mathbf{C}$$
$$- a_0 \mathit{Sin}\, \mathbf{BC} + b_0 \mathit{Sin}\, \mathbf{CA} - c_0 \mathit{Sin}\, \mathbf{AB}.$$

Let $\mathbf{a} = a\alpha^A$, $\mathbf{b} = b\beta^B$, $\mathbf{c} = c\gamma^C$.

the above expressions become

$$\cos \mathbf{abc} = abc \left\{ \begin{array}{l} \cos A \cos B \cos C - \cos A \sin B \sin C \cos \beta\gamma \\ \quad - \cos B \sin C \sin A \cos \gamma\alpha - \cos C \sin A \sin C \cos \alpha\beta \\ \quad + \sin A \sin B \sin C \sin \alpha\beta \cos \overline{\alpha\beta}\gamma \end{array} \right\}$$

and

$$\mathit{Sin}\, \mathbf{abc} = abc \left\{ \begin{array}{l} \cos B \cos C \sin A \cdot \alpha + \cos C \cos A \sin B \cdot \beta \\ + \cos A \cos B \sin C \cdot \gamma \\ - \sin A \sin B \sin C\, (\cos \beta\gamma \cdot \alpha - \cos \gamma\alpha \cdot \beta + \cos \alpha\beta \cdot \gamma) \\ - \cos A \sin B \sin C \sin \beta\gamma \cdot \overline{\beta\gamma} \\ + \cos B \sin C \sin A \sin \gamma\alpha \cdot \overline{\gamma\alpha} \\ - \cos C \sin A \sin B \sin \alpha\beta \cdot \overline{\alpha\beta} \end{array} \right\}$$

As all the terms are evidently symmetrical with respect to β, with the exception of the fifth, it follows that $(\mathbf{ab})\mathbf{c} = \mathbf{a}(\mathbf{bc})$ provided

$$\sin \alpha\beta \cos \overline{\alpha\beta}\gamma \text{ is equal to } \sin \beta\gamma \cos \overline{\alpha\beta}\gamma;$$

but this is a known truth. Hence in this species of multiplication the mode of association of the factors is indifferent.

When **a**, **b** and **c** are coplanar, $\alpha = \beta = \gamma$; and

$$\cos \alpha^{A+B+C} = \cos A \cos B \cos C - \cos A \sin B \sin C - \cos B \sin C \sin A - \cos C \sin A \sin B,$$

and

$$\sin \alpha^{A+B+C} = \cos B \cos C \sin A + \cos C \cos A \sin B + \cos A \cos B \sin C - \sin A \sin B \sin C,$$

which are identical with the formulæ in plane trigonometry.

If further $A = B = C$,

$$\alpha^{3A} = \cos^3 A - 3\cos A \sin^2 A + \left\{ 3\cos^2 A \sin A - \sin^3 A \right\} \alpha^{\frac{\pi}{2}}$$

Let $A = B = C = \frac{\pi}{2}$; then

$$\alpha^{\frac{\pi}{2}} \beta^{\frac{\pi}{2}} \gamma^{\frac{\pi}{2}} = \sin \alpha\beta \cos \overline{\alpha\beta}\gamma + \left\{ -\cos \beta\gamma \cdot \alpha + \cos \gamma\alpha \cdot \beta - \cos \alpha\beta \cdot \gamma \right\}^{\frac{\pi}{2}}$$

Finite rotation.—The effect of a finite rotation on a line is in general not an algebraic product. Let α be the axis and θ the amount of the rotation, **R** a line of length r and axis ρ. Then (fig. 17)

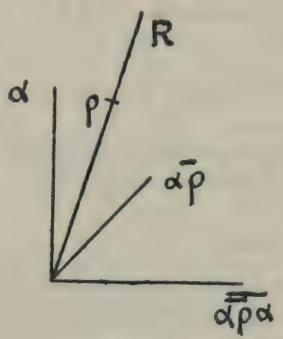

FIG. 17.

$$\alpha^{\theta}\mathbf{R} = r \left\{ \cos \alpha\rho \cdot \alpha + \sin \alpha\rho \sin \theta \cdot \overline{\alpha\rho} + \sin \alpha\rho \cos \theta \cdot \overline{\overline{\alpha\rho}\alpha} \right\}$$

The effect of a subsequent rotation β^{ϕ} is got by applying the same rule to each of the components of **R** in its new position.

In the expression for the quaternion $\alpha^A \beta^B \gamma^C$, let $\alpha^A = \gamma^{-C}$; it will be found on making the reductions that

$$\gamma^{-C}\beta^B\gamma^C = \cos B + \sin B \left\{ \begin{array}{l} \cos^2 C \cdot \beta - \sin^2 C \sin \gamma\beta \cdot \overline{\overline{\gamma\beta}\gamma} + \sin^2 C \cos \gamma\beta \cdot \gamma \\ \qquad 2\sin C \cos C \sin \gamma\beta \cdot \overline{\gamma\beta}; \end{array} \right\}$$

$$= \cos B + \sin B \left\{ \begin{array}{l} \cos \gamma\beta \cdot \gamma + 2\sin C \cos C \sin \gamma\beta \cdot \overline{\gamma\beta} \\ \qquad + (\cos^2 C - \sin^2 C) \sin \gamma\beta \cdot \overline{\overline{\gamma\beta}\gamma} \end{array} \right\}$$

$$= (\gamma^{2C}\beta)^B.$$

Thus the effect of $\gamma^{-C}\ (\ )\ \gamma^{C}$ upon the quaternion β^{B} is to rotate its axis by an angle of $2C$ round γ. Hence the effect of a rotation α^{θ} upon any line $r\rho$ is

$$r\alpha^{\theta}\rho = r\alpha^{-\frac{\theta}{2}}\rho^{\frac{\pi}{2}}\alpha^{\frac{\theta}{2}}.$$

The effect of a subsequent rotation β^{ϕ} is

$$\beta^{\frac{\phi}{2}}\alpha^{\frac{\theta}{2}}\rho = \beta^{-\frac{\phi}{2}}(\alpha^{-\frac{\theta}{2}}\rho^{\frac{\pi}{2}}\alpha^{\frac{\theta}{2}})\beta^{\frac{\phi}{2}}$$

$$= (\beta^{-\frac{\phi}{2}}\alpha^{-\frac{\theta}{2}})\ \rho^{\frac{\pi}{2}}\ (\alpha^{\frac{\theta}{2}}\beta^{\frac{\phi}{2}})$$

for the multiplication may be associated in any manner. Now $\beta^{-\frac{\phi}{2}}\alpha^{-\frac{\theta}{2}}$ is the reciprocal of $\alpha^{\frac{\theta}{2}}\beta^{\frac{\phi}{2}}$; hence the axis of the rotation $\alpha^{\theta}\beta^{\phi}$ is the same as that of the versor $\alpha^{\frac{\theta}{2}}\beta^{\frac{\phi}{2}}$ and its angle is double that of the versor.

DE MOIVRE'S THEOREM.

It has been shown that $\alpha^{A}\alpha^{B} = \alpha^{A+B}$; it follows that n being any number whole or fractional,

$$(\alpha^{\theta})^{n} = \alpha^{n\theta}.$$

Hence by decomposing into component quaternions,

$$\cos n\theta + \sin n\theta \cdot \alpha^{\frac{\pi}{2}} = (\cos\theta + \sin\theta \cdot \alpha^{\frac{\pi}{2}})^{n}$$

$$= \cos^{n}\theta - \frac{n(n-1)}{1\cdot 2}\cos^{n-2}\theta\sin^{2}\theta +$$

$$+ \left\{ n\cos^{n-1}\theta\sin\theta - \frac{n(n-1)(n-2)}{1\cdot 2\cdot 3}\cos^{n-3}\theta\sin^{3}\theta + \right\}\alpha^{\frac{\pi}{2}}$$

The component $\cos n\theta$ having an indefinite axis is equal to the sum of the components which have an indefinite axis and $\sin n\theta$ which has a definite axis is equal to the sum of the components having the same definite axis.

When the value of θ is not restricted to be less than a revolution, let

$$\alpha^{\theta} = \alpha^{2r\pi+\phi}$$

where φ is less than a revolution. Then

$$(\alpha^{\theta})^{n} = \alpha^{2rn\pi+n\phi} = \alpha^{2rn\pi}(\cos\varphi + \sin\varphi \cdot \alpha^{\frac{\pi}{2}})^{n}$$

The quaternion $(\alpha^{\theta}\beta^{\phi})^{n}$ may be expanded in a similar manner. For

$$(\alpha^{\theta}\beta^{\phi})^{n} = (a_0 + \mathbf{A}^{\frac{\pi}{2}})^{n},$$

where

$$a_0 = \cos\theta\cos\varphi - \sin\theta\sin\varphi\cos\alpha\beta$$

and

$$\mathbf{A} = \cos\varphi\sin\theta\cdot\alpha + \cos\theta\sin\varphi\cdot\beta - \sin\theta\sin\varphi\sin\alpha\beta\cdot\overline{\alpha\beta}.$$

But it is not true that

$$(\alpha^{\theta}\beta^{\phi})^{n} = \alpha^{n\theta}\beta^{n\phi};$$

for such law of indices assumes that the factors are commutative.

Expansion of $\cos^n\theta$ and $\sin^n\theta$ in cosines or sines of multiples of θ.

Since

$$a^{n\theta} = \cos n\theta + \sin n\theta \cdot a^{\frac{\pi}{2}}$$

and

$$a^{-n\theta} = \cos n\theta - \sin n\theta \cdot a^{\frac{\pi}{2}};$$

$a^{n\theta} + a^{-n\theta} = 2\cos n\theta$ and $a^{n\theta} - a^{-n\theta} = 2\sin n\theta \cdot a^{\frac{\pi}{2}}$.

Now

$$(a^{\theta} + a^{-\theta})^n = a^{n\theta} + a^{-n\theta} + n\,(a^{(n-2)\theta} + a^{-(n-2)\theta}) + \text{etc.},$$

therefore

$$2^{n-1}\cos^n\theta = \cos n\theta + n\cos(n-2)\theta + \text{etc.}$$

When n is odd,

$$(a^{\theta} - a^{-\theta})^n = a^{n\theta} - a^{-n\theta} - n\,(a^{(n-2)\theta} - a^{-(n-2)\theta}) + \text{etc.},$$

therefore

$$2^{n-1}\sin^n\theta \cdot a^{\frac{n-1}{2}\pi} = \sin n\theta - n\sin(n-2)\theta +$$

When n is even,

$$(a^{\theta} - a^{-\theta})^n = a^{n\theta} + a^{-n\theta} - n\,(a^{(n-2)\theta} + a^{-(n-2)\theta}) +$$

therefore

$$2^{n-1}\sin^n\theta \cdot a^{\frac{n}{2}\pi} = \cos n\theta - n\cos(n-2)\theta +$$

QUATERNION EXPONENTIALS.

Expression of a versor as an exponential.

The versor $a^{\theta} = \cos\theta + \sin\theta \cdot a^{\frac{\pi}{2}}$;

but $\cos\theta = 1 - \frac{\theta^2}{\lfloor 2} + \frac{\theta^4}{\lfloor 4} -$

$$= 1 + \frac{(\theta \cdot a^{\frac{\pi}{2}})^2}{\lfloor 2} + \frac{(\theta \cdot a^{\frac{\pi}{2}})^4}{\lfloor 4};$$

and $\sin\theta = \theta - \frac{\theta^3}{\lfloor 3} + \frac{\theta^5}{\lfloor 5} -$

therefore $\sin\theta \cdot a^{\frac{\pi}{2}} = \theta \cdot a^{\frac{\pi}{2}} + \frac{(\theta \cdot a^{\frac{\pi}{2}})^3}{\lfloor 3} + \frac{(\theta \cdot a^{\frac{\pi}{2}})^5}{\lfloor 5} + ;$

therefore $a^{\theta} = 1 + \theta \cdot a^{\frac{\pi}{2}} + \frac{(\theta \cdot a^{\frac{\pi}{2}})^2}{\lfloor 2} +$

$$= \varepsilon^{\theta \cdot a^{\frac{\pi}{2}}}$$

Similarly $a^{-\theta} = \varepsilon^{-\theta \cdot a^{\frac{\pi}{2}}} = \varepsilon^{\theta \cdot a^{\frac{3\pi}{2}}}$

Let n be any even number; then

$$a^{n\pi} = 1 = \varepsilon^{n\pi \cdot a^{\frac{\pi}{2}}} = 1 + n\pi \cdot a^{\frac{\pi}{2}} - \frac{(n\pi)^2}{\lfloor 2} + \frac{(n\pi)^3}{\lfloor 3} a^{3\frac{\pi}{2}} + \text{etc.};$$

therefore $$1 = 1 - \frac{(n\pi)^2}{\lfloor 2} + \frac{(n\pi)^4}{\lfloor 4} -$$

and $$0 = n\pi - \frac{(n\pi)^3}{\lfloor 3} + \text{etc.}$$

If n is an odd number

$$-1 = 1 - \frac{(n\pi)^2}{\lfloor 2} + \frac{(n\pi)^4}{\lfloor 4} - \text{etc.}$$

$$0 = n\pi - \frac{(n\pi)^3}{\lfloor 3} + \text{etc.}$$

Logarithm of a quaternion.

The general quaternion is $ra^{\theta} = r\varepsilon^{\theta \cdot a^{\frac{\pi}{2}}} = \varepsilon^{\log r + \theta \cdot a^{\frac{\pi}{2}}}$

Hence $$\log (ra^{\theta}) = \log r + \theta \cdot a^{\frac{\pi}{2}}.$$

If the quaternion is given as $\mathfrak{a} = a + b \cdot a^{\frac{\pi}{2}}$

then $$\log \mathfrak{a} = \tfrac{1}{2} \log (a^2 + b^2) + \tan^{-1} \frac{b}{a} \cdot a^{\frac{\pi}{2}}$$

Hence $$\log 1 = 0 \quad \text{but } \log (-1) = \pi \cdot a^{\frac{\pi}{2}}.$$

The more general form is $\mathfrak{a} = a^{2r\pi} (a + b \cdot a^{\frac{\pi}{2}})$,

and $$\log \mathfrak{a} = \tfrac{1}{2} \log (a^2 + b^2) + \left(\tan^{-1} \frac{b}{a} + 2r\pi\right) \cdot a^{\frac{\pi}{2}}$$

Quaternion exponential.

Since

$$a^{\theta} = \cos\theta + \sin\theta \cdot a^{\frac{\pi}{2}}$$

$$\varepsilon^{a^{\theta}} = \varepsilon^{\cos\theta + \sin\theta \cdot a^{\frac{\pi}{2}}} = \varepsilon^{\cos\theta} \varepsilon^{\sin\theta \cdot a^{\frac{\pi}{2}}},$$

$$= \left(1 + \cos\theta + \frac{\cos^2\theta}{\lfloor 2} + \right) \left(1 + \sin\theta \cdot a^{\frac{\pi}{2}} + \frac{\sin^2\theta \cdot a^{\pi}}{\lfloor 2} + \right)$$

$$= \left(1 + \cos\theta + \frac{\cos^2\theta}{\lfloor 2} + \right) \left(1 - \frac{\sin^2\theta}{\lfloor 2} + \frac{\sin^4\theta}{\lfloor 4} - \right)$$

$$+ \left(1 + \cos\theta + \frac{\cos^2\theta}{\lfloor 2} + \right) \left(\sin\theta - \frac{\sin^3\theta}{\lfloor 3} + \right) . a^{\frac{\pi}{2}}$$

Let $\theta = \frac{\pi}{2}$; then $\varepsilon^{a^{\frac{\pi}{2}}} = a^1$

$$= 1 - \frac{1}{\lfloor 2} + \frac{1}{\lfloor 4} -$$

$$+\left\{1-\frac{1}{\underline{|3}}+\frac{1}{\underline{|5}}-\right\}\cdot\alpha^{\frac{\pi}{2}}.$$

Let $\theta=0$; then $\varepsilon^{\alpha 0}=\varepsilon$

SCALAR DIFFERENTIATION.

By scalar differentiation is meant differentiation with respect to a variable which has no axis, or the only axis considered; for instance, time, or length along a curve, or distance along an axis if one axis only is considered.

Differentiation of a vector.—Consider the radius-vector of a point, $\mathbf{R}=r\rho$, where r denotes the length and ρ the axis. The velocity-vector $\frac{\mathbf{dR}}{dt}$ is obtained by differentiating $r\rho$ in the same manner as an ordinary product;

$$\frac{\mathbf{dR}}{dt}=\frac{dr}{dt}\rho+r\frac{\mathbf{d}\rho}{dt},$$

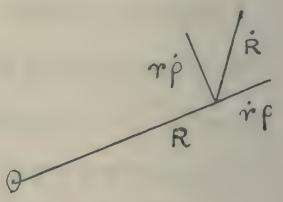

FIG. 18.

Here a small Roman **d** is used to denote a directed differential. The whole velocity may be denoted in accordance with the fluxional notation by $\dot{\mathbf{R}}$, the component along the radius vector by $\dot{r}\rho$ and the component transverse to the radius-vector by $r\dot{\rho}$ (fig. 18). By differentiating each component of the velocity according to the same rule, we obtain the acceleration-vector

$$\frac{\mathbf{d}^2\mathbf{R}}{dt^2}=\frac{d^2r}{dt^2}\rho+2\frac{dr}{dt}\frac{\mathbf{d}\rho}{dt}+r\frac{\mathbf{d}^2\rho}{dt^2}$$

or

$$\ddot{\mathbf{R}}=\ddot{r}\rho+2\dot{r}\dot{\rho}+r\ddot{\rho}$$

The angular velocity $\frac{\mathbf{d}\rho}{dt}$ may be analyzed into $\frac{d\rho}{dt}\bar{\rho}$, where $\frac{d\rho}{dt}$ denotes its ratio magnitude and $\bar{\rho}$ its direction, which is perpendicular to ρ.

Hence $\frac{\mathbf{dR}}{dt}=\frac{dr}{dt}\cdot\rho+r\frac{d\rho}{dt}\cdot\bar{\rho}$;

and $\frac{\mathbf{d}^2\mathbf{R}}{dt^2}=\frac{d^2r}{dt^2}\cdot\rho+\left(2\frac{dr}{dt}\frac{d\rho}{dt}+r\frac{d^2\rho}{dt^2}\right)\cdot\bar{\rho}+r\frac{d\rho}{dt}\frac{d\bar{\rho}}{dt}\cdot\bar{\bar{\rho}}$

The direction of the third component $\bar{\bar{\rho}}$ is perpendicular to the perpendicular to ρ; in a plane it is $=-\rho$, and then

$$\frac{\mathbf{d}^2\mathbf{R}}{dt^2}=\left\{\frac{d^2r}{dt^2}-r\left(\frac{d\rho}{dt}\right)^2\right\}\cdot\rho+\left\{2\frac{dr}{dt}\frac{d\rho}{dt}+r\frac{d^2\rho}{dt^2}\right\}\cdot\bar{\rho}.$$

The expression for the magnitude of $\frac{\mathbf{dR}}{dt}$ is $\frac{ds}{dt}$ and for its axis $\frac{\mathbf{dR}}{ds}$; thus $\frac{\mathbf{dR}}{dt}=\frac{ds}{dt}\frac{\mathbf{dR}}{ds}$, and by applying the rule for differentiating a vector,

$$\frac{\mathbf{d}^2\mathbf{R}}{dt^2}=\frac{d^2s}{dt^2}\frac{\mathbf{dR}}{ds}+\left(\frac{ds}{dt}\right)^2\frac{\mathbf{d}^2\mathbf{R}}{ds^2},$$

the former component expressing the acceleration along the tangent, and the latter that along the radius of curvature.

Let $\mathbf{C} = u \cdot \xi + v \cdot \eta + w \cdot \zeta$ where each of the six elements may vary, then

$$\frac{\mathrm{d}\mathbf{C}}{dt} = \frac{du}{dt} \cdot \xi + \frac{dv}{dt} \cdot \eta + \frac{dw}{dt} \cdot \zeta + u \cdot \frac{\mathrm{d}\xi}{dt} + v \cdot \frac{\mathrm{d}\eta}{dt} + w \cdot \frac{\mathrm{d}\zeta}{dt}$$

If ξ, η and ζ are constant, the second expression vanishes. The simplest case is

$$\mathbf{R} = xi + yj + zk$$

giving $$\frac{\mathrm{d}\mathbf{R}}{dt} = \frac{dx}{dt} i + \frac{dy}{dt} j + \frac{dz}{dt} k;$$

and for the same reason, it follows that

$$\frac{\mathrm{d}^2\mathbf{R}}{dt^2} = \frac{d^2x}{dt^2} i + \frac{d^2y}{dt^2} j + \frac{d^2z}{dt^2} k.$$

Products.—A velocity-vector, or an acceleration-vector is combined the same as a simple vector. For example,

$$\mathbf{R} \frac{\mathrm{d}\mathbf{R}}{dt} = (xi + yj + zk) \left(\frac{dx}{dt} i + \frac{dy}{dt} j + \frac{dz}{dt} k \right)$$

$$= x \frac{dx}{dt} + y \frac{dy}{dt} + z \frac{dz}{dt} + \begin{vmatrix} x & y & z \\ \frac{dx}{dt} & \frac{dy}{dt} & \frac{dz}{dt} \\ i & j & k \end{vmatrix}$$

Also $$\mathbf{R} \frac{\mathrm{d}\mathbf{R}}{dt} = r\rho \left(\frac{dr}{dt} \rho + r \frac{\mathrm{d}\rho}{dt} \right)$$

$$= r \frac{dr}{dt} + r^2 \rho \frac{\mathrm{d}\rho}{dt},$$

thus $$cos\, \mathbf{R} \frac{\mathrm{d}\mathbf{R}}{dt} = r \frac{dr}{dt} \quad \text{and} \quad Sin\, \mathbf{R} \frac{\mathrm{d}\mathbf{R}}{dt} = r^2 \rho \frac{\mathrm{d}\rho}{dt}$$

Similarly $$\mathbf{R}^{-1} \frac{\mathrm{d}\mathbf{R}}{dt} = \frac{1}{r} \frac{dr}{dt} + \rho \frac{\mathrm{d}\rho}{dt}.$$

Also $$\mathbf{R} \frac{\mathrm{d}^2\mathbf{R}}{dt^2} = r\rho \left(\frac{d^2r}{dt^2} \rho + 2 \frac{dr}{dt} \frac{\mathrm{d}\rho}{dt} + r \frac{\mathrm{d}^2\rho}{dt^2} \right),$$

$$= r \frac{d^2r}{dt^2} + 2r \frac{dr}{dt} \rho \frac{\mathrm{d}\rho}{dt} + r^2 \rho \frac{\mathrm{d}^2\rho}{dt^2};$$

thus $$cos\, \mathbf{R} \frac{\mathrm{d}^2\mathbf{R}}{dt^2} = r \frac{d^2r}{dt^2} + r^2\, cos \left(\rho \frac{\mathrm{d}^2\rho}{dt^2} \right)$$

and $$Sin\, \mathbf{R} \frac{\mathrm{d}^2\mathbf{R}}{dt^2} = 2r \frac{dr}{dt} \rho \frac{\mathrm{d}\rho}{dt} + r^2\, Sin \left(\rho \frac{\mathrm{d}^2\rho}{dt^2} \right)$$

Differentiation of a product of two vectors.—Let $\mathbf{B} = b\beta$ and $\mathbf{C} = c\gamma$ be any two vectors; it is required to differentiate their product $\mathbf{BC}$ with respect to time or any scalar variable. The rule is to apply the rule of differentiation (p. 104) to each factor of the product, supposing the other constant, and preserving the order of the factors. This is a generalization of the rule for the ordinary algebraic product. Thus

$$\mathrm{d} \frac{(\mathbf{BC})}{dt} = \frac{\mathrm{d}\mathbf{B}}{dt} \mathbf{C} + \mathbf{B} \frac{\mathrm{d}\mathbf{C}}{dt}$$

$$= \left(\frac{db}{dt} \beta + b \frac{\mathrm{d}\beta}{dt} \right) c\gamma + b\beta \left(\frac{dc}{dt} \gamma + c \frac{\mathrm{d}\gamma}{dt} \right)$$

$$= \left(c \frac{db}{dt} + b \frac{dc}{dt} \right) \beta\gamma + bc \left(\frac{\mathrm{d}\beta}{dt} \gamma + \beta \frac{\mathrm{d}\gamma}{dt} \right)$$

Hence $\frac{\mathrm{d}\mathbf{B}^2}{dt} = 2b\frac{db}{dt} = 2\cos\mathbf{B}\frac{\mathrm{d}\mathbf{B}}{dt}$

Let $\mathbf{B} = ai + bj + ck, \quad \mathbf{C} = ui + vj + wk;$

then $\mathbf{B}\,\mathbf{C} = au + bv + cw + \begin{vmatrix} a & b & c \\ u & v & w \\ i & j & k \end{vmatrix},$

and $\frac{\mathrm{d}(\mathbf{BC})}{dt} = \frac{da}{dt}u + \frac{db}{dt}v + \frac{dc}{dt}w$

$+ a\frac{du}{dt} + b\frac{dv}{dt} + c\frac{dw}{dt}$

$+ \begin{vmatrix} \frac{da}{dt} & \frac{db}{dt} & \frac{dc}{dt} \\ u & v & w \\ i & j & k \end{vmatrix} + \begin{vmatrix} a & b & c \\ \frac{du}{dt} & \frac{dv}{dt} & \frac{dw}{dt} \\ i & j & k \end{vmatrix}$

Hence $\frac{\mathrm{d}\mathbf{B}^2}{dt} = 2\left(a\frac{da}{dt} + b\frac{db}{dt} + c\frac{dc}{dt}\right)$

Differentiation of a product of three vectors.—Let **B, C, D** be any three vectors, **B** and **C** having elements as before, and $\mathbf{D} = d\delta = fi + gj + hk.$

Then $\frac{\mathrm{d}(\mathbf{BCD})}{dt} = \frac{\mathrm{d}\mathbf{B}}{dt}\mathbf{CD} + \mathbf{B}\frac{\mathrm{d}\mathbf{C}}{dt}\mathbf{D} + \mathbf{BC}\frac{\mathrm{d}\mathbf{D}}{dt}$

where, not only must the order of the factors, but also their mode of association be preserved.

Let $\mathbf{C} = \mathbf{B}$, then $\frac{\mathrm{d}(\mathbf{B}^2\mathbf{D})}{dt} = 2b\frac{db}{dt}\mathbf{D} + b^2\frac{\mathrm{d}\mathbf{D}}{dt}$

If further $\mathbf{D} = \mathbf{B}$, then $\frac{\mathrm{d}\mathbf{B}^3}{dt} = 2b^2\frac{db}{dt}\beta + b^2\frac{\mathrm{d}\mathbf{B}}{dt}$

Differentiation of a power of a vector.—It is evident that

$$\frac{\mathrm{d}\mathbf{B}^2}{dt} = 2\cos\left(\mathbf{B}\frac{\mathrm{d}\mathbf{B}}{dt}\right)$$

and

$$\frac{\mathrm{d}\mathbf{B}^3}{dt} = 2\cos\left(\mathbf{B}\frac{\mathrm{d}\mathbf{B}}{dt}\right)\mathbf{B} + \mathbf{B}^2\frac{\mathrm{d}\mathbf{B}}{dt}$$

are true generalizations of the differentiation which occurs in ordinary algebra. For if the quantity **B** has a constant axis, as is supposed in that algebra, $\frac{\mathrm{d}\mathbf{B}^2}{dt}$ becomes $2\mathbf{B}\frac{\mathrm{d}\mathbf{B}}{dt}$, and $\frac{\mathrm{d}\mathbf{B}^3}{dt}$ becomes $3\mathbf{B}^2\frac{d\mathbf{B}}{dt}$. According to the principles of quaternions a minus sign would be introduced.

It may be shown generally that when n is even,

$$\frac{\mathrm{d}\mathbf{B}^n}{dt} = nb^{n-1}\frac{db}{dt};$$

and when n is odd,

$$\frac{\mathrm{d}\mathbf{B}^n}{dt} = (n-1)\,b^{n-2}\frac{db}{dt}\mathbf{B} + b^{n-1}\frac{\mathrm{d}\mathbf{B}}{dt}.$$

This holds also, when n is negative; for instance, $n = -1$. For by direct differentiation

$$\frac{\mathrm{d}\mathbf{B}^{-1}}{dt} = \frac{\mathrm{d}}{dt}\left(\frac{\mathbf{B}}{b^2}\right) = -\frac{2\frac{db}{dt}}{b^3}\mathbf{B} + \frac{1}{b^2}\frac{\mathrm{d}\mathbf{B}}{dt},$$

which agrees with the formula. The simplicity of this process may be compared with that given in Tait's *Treatise on Quaternions*, p. 97, where a vector is treated as a quadrantal versor.

Differentiation of a quaternion.—Let $\mathbf{r} = r\varphi^{\theta}$ be any quaternion; then

$$\frac{\mathbf{dr}}{dt} = \frac{dr}{dt}\varphi^{\theta} + r\frac{d}{dt}(\varphi^{\theta});$$

we have to find how to differentiate the versor φ^{θ}, supposing φ to vary perpendicular to an initial line.

Since

$$\varphi^{\theta} = cos\,\theta + sin\,\theta \cdot \varphi^{\frac{\pi}{2}}$$

$$\frac{\mathbf{d}}{dt}\varphi^{\theta} = -sin\,\theta\frac{d\theta}{dt} + \left\{cos\,\theta\frac{d\theta}{dt}\cdot\varphi + sin\,\theta\frac{\mathbf{d}\phi}{dt}\right\}^{\frac{\pi}{2}}$$

$$= \frac{d\theta}{dt}\varphi^{\theta+\frac{\pi}{2}} + sin\theta\cdot\frac{\mathbf{d}\phi}{dt}^{\frac{\pi}{2}}.$$

Hence

$$\frac{\mathbf{dr}}{dt} = \frac{dr}{dt}\varphi^{\theta} + r\frac{d\theta}{dt}\varphi^{\theta+\frac{\pi}{2}} + r\,sin\,\theta\frac{\mathbf{d}\phi}{dt}^{\frac{\pi}{2}}.$$

By applying the rule found to each of the components of $\frac{\mathbf{dr}}{dt}$ we obtain

$$\frac{\mathbf{d}^2\mathbf{r}}{dt^2} = \left\{\frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2\right\}\varphi^{\theta} + \left\{2\frac{dr}{dt}\frac{d\theta}{dt} + r\frac{d^2\theta}{dt^2}\right\}\varphi^{\theta+\frac{\pi}{2}}$$

$$+2\left\{\frac{dr}{dt}sin\,\theta + r\frac{d\theta}{dt}cos\,\theta\right\}\frac{\mathbf{d}\phi}{dt}^{\frac{\pi}{2}} + r\,sin\,\theta\frac{\mathbf{d}^2\phi}{dt^2}^{\frac{\pi}{2}}$$

Since $\frac{\mathbf{d}\phi}{dt} = \frac{d\phi}{dt}\overline{\varphi}$ where $\overline{\varphi}$ denotes an axis perpendicular to φ;

$$\frac{\mathbf{d}^2\phi}{dt^2} = \frac{d^2\phi}{dt^2}\overline{\varphi} + \frac{d\phi}{dt}\frac{d\overline{\phi}}{dt}\overline{\overline{\varphi}}.$$

In the case of polar coördinates φ is always perpendicular to a constant axis a; then

$$\overline{\varphi} = \overline{\varphi a} \quad \text{and} \quad \overline{\overline{\varphi}} = -\varphi \quad \text{and} \quad \frac{d\overline{\phi}}{dt} = \frac{d\phi}{dt}.$$

Hence the components for the acceleration in terms of polar coördinates

$$\left\{\frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 - r\,sin^2\,\theta\left(\frac{d\phi}{dt}\right)^2\right\}\varphi^{\theta}$$

$$+\left\{2\frac{dr}{dt}\frac{d\theta}{dt} + r\frac{d^2\theta}{dt} - r\,sin\,\theta\,cos\,\theta\,\dot{\varphi}^2\right\}\varphi^{\theta+\frac{\pi}{2}}$$

$$+\left\{2\frac{dr}{dt}sin\,\theta\frac{d\phi}{dt} + 2r\,cos\,\theta\frac{d\theta}{dt}\frac{d\phi}{dt} + r\,sin\,\theta\frac{d^2\phi}{dt^2}\right\}\overline{\varphi a}^{\frac{\pi}{2}}.$$

MATRICES.

Dyad.—In order to specify a homogeneous strain the conception of the dyad is required. It specifies the manner in which all lines originally

parallel to a given direction are changed in magnitude and direction. If a line **A** (fig. 19) is changed into **B**, and all lines having the axis α are changed homogeneously, such change is expressed by the dyad $\mathbf{A}^{-1}\mathbf{B}$, that is, $\frac{b}{a}\alpha\beta$. Thus, a dyad expresses an arithmetical ratio combined with a change of axis. If such strain is followed by another specified by

$$\mathbf{B}^{-1}\mathbf{C} = \frac{c}{b}\beta\gamma,$$

the result of the two is found by taking the product of the dyads which means multiplying the ratios and adding the angles. Thus,

$$(\mathbf{A}^{-1}\mathbf{B})\ (\mathbf{B}^{-1}\mathbf{C}) = \frac{b}{a}\frac{c}{b}\ (\alpha\beta)\ (\beta\gamma) = \frac{c}{a}\alpha\gamma.$$

In ordinary algebra it is indifferent whether a ratio is written $a^{-1}b$ or ba^{-1}, because no angle is involved. But in specifying a physical ratio,

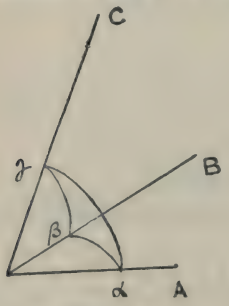

FIG. 19.

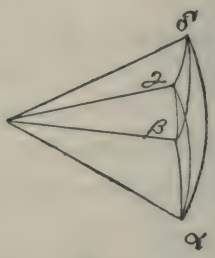

FIG. 20.

where an angle is involved, it is convenient to choose an order; and the proper order appears to be that which specifies the order of the change in the order of writing.

The conjugate dyad is

$$\mathbf{B}\mathbf{A}^{-1} = \frac{b}{a}\beta\alpha;$$

and the reciprocal dyad is

$$\mathbf{B}^{-1}\mathbf{A} = \frac{a}{b}\beta\alpha,$$

for

$$(\mathbf{B}^{-1}\mathbf{A})\ (\mathbf{A}^{-1}\mathbf{B}) = \frac{a}{b}\frac{b}{a}\ (\beta\alpha)\ (\alpha\beta) = 1.$$

If a third change follows specified by

$$\mathbf{C}^{-1}\mathbf{D} = \frac{d}{c}\gamma\delta,$$

then the result of the three is

$$(\mathbf{A}^{-1}\mathbf{B})\ (\mathbf{B}^{-1}\mathbf{C})\ (\mathbf{C}^{-1}\mathbf{D}) = \frac{b}{a}\frac{c}{b}\frac{d}{c}\ (\alpha\beta)\ (\beta\gamma)\ \gamma\delta).$$
$$= \frac{d}{a}\alpha\delta.$$

The difference between the multiplication of dyads and of quaternions is that in the former the angles are localized and each succeeding one starts from the end of the preceding (fig. 20). The multiplication of quaternions is indifferent with respect to association, it follows *a fortiori* that

the multiplication of dyads is also indifferent. This means that we get the same angle $a\delta$ whether we first take the sum of $a\beta$ and $\beta\gamma$ which is $a\gamma$ and then the sum of $a\gamma$ and $\gamma\delta$; or whether we first take the sum of $\beta\gamma$ and $\gamma\delta$ which is $\beta\delta$ and then the sum of $a\beta$ and $\beta\delta$. In a product of three vectors, the two non-associated vectors form a dyad; that is, in $(\mathbf{AB})\mathbf{C}$, the relation of $\mathbf{B}$ to $\mathbf{C}$ is $bc\,\beta\gamma$.

Notation for a matrix.—A homogeneous strain may be considered as a physical quantity, and as such denoted by a single symbol Φ. It is equal to the sum of three dyads, one for each independent axis of space; and is expressed quite generally by the sum of the dyads for each of three mutually rectangular axes. In the figure (fig. 21) the dyad for the axis k is represented. An axis k receives an increment in its own direction, in the direction of j and in the direction of k.

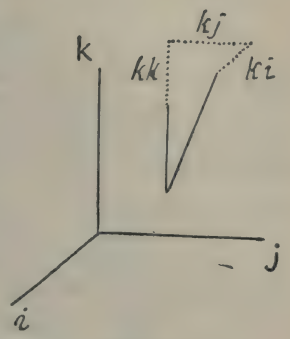

FIG. 21.

Such sum of three dyads is equivalent to the linear-vector operator of Hamilton, or the matrix of algebra. The notation used by Cayley in his *Memoir on Matrices* is

$$(X, Y, Z) = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} (x, y, z);$$

which represents the coëfficients of a linear transformation separated from the variables, but does not express explicitly the ratios.

As a sum of three mutually rectangular dyads

$$\begin{aligned} \Phi &= (1i)^{-1}\,\mathbf{A} + (1j)^{-1}\,\mathbf{B} + (1k)^{-1}\,\mathbf{C}; \\ &= (1i)^{-1}\,(a_1 i + a_2 j + a_3 k) \\ &+ (1j)^{-1}\,(b_1 i + b_2 j + b_3 k) \\ &+ (1k)^{-1}\,(c_1 i) + c_2 j + c_3 k); \\ &= a_1 ii + a_2 ij + a_3 ik \\ &+ b_1 ji + b_2 jj + b_3 jk \\ &+ c_1 ki + c_2 kj + c_3 kk. \end{aligned}$$

In the last expression, where the ratios are expressed, not merely indicated, a_1 means the former a_1 divided by 1, and therefore is a ratio not a length; and ii denotes the angle between the axis i and i, which is nought, while ij denotes that between i and j. Hence, in such an expression as

$$\Phi = i\mathbf{A} + j\mathbf{B} + k\mathbf{C}$$

$\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$ are ratio-vectors.

Conjugate matrix.—The conjugate of Φ, denoted by Φ' is formed by taking the conjugate of each of the elementary ratios; thus,

$$\begin{aligned}\Phi' &= a_1ii + b_1ij + c_1ik \\ &+ a_2ji + b_2jj + c_2jk \\ &+ a_3ki + b_3kj + c_3kk; \\ &= i\,(a_1i + b_1j + c_1k) \\ &+ j\,(a_2i + b_2j + c_2k) \\ &+ k\,(a_3i + b_3j + c_3k).\end{aligned}$$

Ratio for any axis.—The ratio for any axis ρ may be denoted by $\rho r\rho'$ where r denotes the ratio and ρ' the new axis. It is deduced from the three rectangular ratios in the following manner:

$$\rho r\rho' = \rho\Big\{\cos\rho i\,(a_1i + a_2j + a_3k) + \cos\rho j\,(b_1i + b_2j + b_3k) + \cos\rho k\,(c_1i + c_2j + c_3k)\Big\}.$$

Hence any line $R\rho$ becomes

$$rR\rho' = R\,(\cos\rho i\cdot\mathbf{A} + \cos\rho j\cdot\mathbf{B} + \cos\rho k\cdot\mathbf{C}).$$

Product of line and matrix.—Let

$$\mathbf{R} = xi + yj + zk$$

denote any line; then

$$\begin{aligned}\mathbf{R}\Psi &= \mathbf{R}\,(i\mathbf{A} + j\mathbf{B} + k\mathbf{C}) \\ &= (xi + yj + zk)\,(i\mathbf{A} + j\mathbf{B} + k\mathbf{C})\end{aligned}$$

The complete product is the sum of nine partial products of three vectors; the sum of the $\cos\alpha\beta\cdot\gamma$ terms gives the ordinary product, while the sum of the $(Sin\,\alpha\beta)\,\gamma$ terms forms a complementary product. Thus,

$$\mathbf{R}\Psi = x\mathbf{A} + y\mathbf{B} + z\mathbf{C} + \begin{vmatrix} x & y & z \\ i & j & k \\ \mathbf{A} & \mathbf{B} & \mathbf{C}\end{vmatrix}.$$

Here we have a product consisting of two parts analogous to the two parts of the product of two vectors, the former may be denoted by $\cos\mathbf{R}\Psi$, the latter by $Sin\,\mathbf{R}\Psi$.

Product of two matrices.

Let
$$\begin{aligned}\Phi = i\,&(a_1i + a_2j + a_3k) \\ + j\,&(b_1i + b_2j + b_3k) \\ + k\,&(c_1i + c_2j + c_3k)\end{aligned}$$

and
$$\begin{aligned}\Psi = i\,&(d_1i + d_2j + d_3k) \\ + j\,&(e_1i + e_2j + e_3k) \\ + k\,&(f_1i + f_2j + f_3k)\end{aligned}$$

The strain which is the resultant of Φ and Ψ applied in the order named is found by compounding the elementary ratios; for example

$$(a_1ii)\;(d_1ii) = a_1d_1ii\;;\quad (a_1ii)\;(d_2ij) = a_1d_2ij.$$

Hence

$$\Phi\,\Psi = i\left\{(a_1d_1 + a_2e_1 + a_3f_1)i + (a_1d_2 + a_2e_2 + a_3f_2)j + (a_1d_3 + a_2e_3 + a_3f_3)k\right\}$$
$$+ j\left\{(b_1d_1 + b_2e_1 + b_3f_1)i + (b_1d_2 + b_2e_2 + b_3f_2)j + (b_1d_3 + b_2e_3 + b_3f_3)k\right\}$$
$$+ k\left\{(c_1d_1 + c_2e_1 + c_3f_1)i + (c_1d_2 + c_2e_2 + c_3f_2)j + (c_1d_3 + c_2e_3 + c_3f_3)k\right\}$$

Hence if $\Phi = i\mathbf{A} + j\mathbf{B} + k\mathbf{C}$,

and $\Psi = i\mathbf{A}' + j\mathbf{B}' + k\mathbf{C}'$;

$$\Phi\Psi = i\left\{\cos\mathbf{AA}'\,i + \cos\mathbf{AB}'\,j + \cos\mathbf{AC}'\,k\right\}$$
$$+ j\left\{\cos\mathbf{BA}'\,i + \cos\mathbf{BB}'\,j + \cos\mathbf{BC}'\,k\right\}$$
$$+ k\left\{\cos\mathbf{CA}'\,i + \cos\mathbf{CB}'\,j + \cos\mathbf{CC}'\,k\right\}$$

Here the product of the two strains is formed from the nature of a strain apart from the effect upon a given line. As the product of three dyads is associative, this product of three strains is also associative.

Complete product of two matrices.—The ordinary product of $\Phi\,\Psi$ contains only twenty-seven terms, the complete product ought to contain eighty-one. The other fifty-four terms form another term, which is expressed by

$$i\left\{\mathit{Sin}\,\mathbf{AA}'\,i + \mathit{Sin}\,\mathbf{AB}'\,j + \mathit{Sin}\,\mathbf{AC}'\,k\right\}$$
$$+ j\left\{\mathit{Sin}\,\mathbf{BA}'\,i + \mathit{Sin}\,\mathbf{BB}'\,j + \mathit{Sin}\,\mathbf{BC}'\,k\right\}$$
$$+ k\left\{\mathit{Sin}\,\mathbf{CA}'\,i + \mathit{Sin}\,\mathbf{CB}'\,j + \mathit{Sin}\,\mathbf{CC}'\,k\right\}$$

Here we have a product of four axes in which the association begins in the middle.

Product of a matrix and its conjugate.—For the conjugate matrix $\mathbf{A}' = \mathbf{A}$, $\mathbf{B}' = \mathbf{B}$, $\mathbf{C}' = \mathbf{C}$.

Hence $\Phi\,\Phi' = i\left\{\mathbf{A}^2\,i + \cos\mathbf{AB}\,j + \cos\mathbf{AC}\,k\right\}$

$$+ j\left\{\cos\mathbf{AB}\,i + \mathbf{B}^2\,j + \cos\mathbf{BC}\,k\right\}$$
$$+ k\left\{\cos\mathbf{AC}\,i + \cos\mathbf{BC}\,j + \mathbf{C}^2\,k\right\}$$

and the complementary product is

$$i\left\{0\,i + \mathit{Sin}\,\mathbf{AB}\,j + \mathit{Sin}\,\mathbf{AC}\,k\right\}$$
$$+ j\left\{\mathit{Sin}\,\mathbf{BA}\,i + 0\,j + \mathit{Sin}\,\mathbf{BC}\,k\right\}$$
$$+ k\left\{\mathit{Sin}\,\mathbf{CA}\,i + \mathit{Sin}\,\mathbf{CB}\,j + 0\,k\right\}$$

Reciprocal of a matrix.—The reciprocal of Φ is denoted by Φ^{-1} ; it is such that

$$\Phi\,\Phi^{-1} = 1\,ii + 1\,jj + 1\,kk.$$

By solving the equations $cos\,\mathbf{AA}' = 1$, $cos\,\mathbf{BA}' = 0$, $cos\,\mathbf{CA}' = 0$; we find

$$\mathbf{A}' = \frac{Sin\,\mathbf{BC}}{vol\,\mathbf{ABC}}$$

Hence

$$\Phi^{-1} = \frac{i\,Sin\,\mathbf{BC} + j\,Sin\,\mathbf{CA} + k\,Sin\,\mathbf{AB}}{vol\,\mathbf{ABC}}$$

Second power of a matrix.—If $\Psi = \Phi$; then the second power of the ordinary product is

$$\begin{aligned}\Phi^2 = i\Big\{ &(a_1{}^2 + a_2b_1 + a_3c_1)i + (a_1a_2 + a_2b_2 + a_3c_2)j \\ &+(a_1a_3 + a_2b_3 + a_3c_3)\,k\Big\} \\ +j\Big\{ &(b_1a_1 + b_2b_1 + b_3c_1)i + (b_1a_2 + b_2{}^2 + b_3c_2)\,j \\ &+ (b_1a_3 + b_2b_3 + b_3c_3)k\Big\} \\ +k\Big\{ &(c_1a_1 + c_2b_1 + c_3c_1)i + (c_1a_2 + c_2b_2 + c_3c_2)j \\ &+ (c_1a_3 + c_2b_3 + c_3{}^2)\,k\Big\}\end{aligned}$$

Components of a matrix.— A matrix may be resolved into the sum of three components, as

$$\begin{aligned}\Phi = {} & a_1\,ii + b_2\,jj + c_3\,kk \\ & + \tfrac{1}{2}\Big\{(b_3 - c_2)\,jk + (c_1 - a_3)ki + (a_2 - b_1)\,ij\Big\} \\ & + \tfrac{1}{2}\Big\{(b_3 + c_2)\,jk + (c_1 + a_3)\,ki + (a_2 + b_1)\,ij\Big\};\end{aligned}$$

of which the first component expresses elongation, the second rotation, and the third shear.

Invariant functions of a matrix.—

Let

$$\begin{aligned}\Phi = {} & i\,(a_1i + a_2j + a_3k) && (1)\\ & + j\,(b_1i + b_2j + b_3k) && (2)\\ & + k\,(c_1i + c_2j + c_3k) && (3)\end{aligned}$$

By combining the terms of the three ratios according to the rules of vector multiplication we obtain

$$\begin{aligned} & a_1 + a_2\,k - a_3\,j \\ - & b_1k + b_2 + b_3i \\ & c_1j - c_2i + c_3\end{aligned}$$

and by addition we obtain the scalar and vector invariants

$$a_1 + b_2 + c_3 + (b_3 - c_2)i + (c_1 - a_3)j + (a_2 - b_1)k$$

By combining (1) and (2) we form the ratio for the change of a rectangle having the axes i and j;

$$(ij)\left\{a_1b_1 + a_2b_2 + a_3b_3 + (a_1b_2 - a_2b_1)ij + a_2b_3 - a_3b_2)jk + (a_3b_1 - a_1b_3)\,ki\right\}$$

and by combining (2) with (3) and (3) with (1) and adding we obtain a scalar and two vectors

$$a_1b_2 - a_2b_1 + b_2c_3 - b_3c_2 + c_3a_1 - c_1a_3;$$
$$(b_1c_1 + b_2c_2 + b_3c_3)i + (c_1a_1 + c_2a_2 + c_3a_3)j + (a_1b_1 + a_2b_2 + a_3b_3)k;$$
$$\left\{(c_1a_2 - c_2a_1) - (a_3b_1 - a_1b_3)\right\}i + \left\{(a_2b_3 - a_3b_2) - (b_1c_2 - b_2c_1)\right\}j + \left\{(b_3c_1 - b_1c_3) - (c_2a_3 - c_3a_3)\right\}k;$$

By combining (1), (2) and (3) together we get the ratio for the change of a rectangular parallelopiped having the axes i, j, k. The scalar which is the same for the three modes of association is the determinant

$$\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}$$

In this way the physical meaning is evident of the three scalars which occur in the cubic equation.

VECTOR DIFFERENTIATION.

Of a scalar quantity.—Let u denote any scalar quantity, a function of x, y, z; then $(dxi)^{-1}\,du_x$ denotes its growth per unit of distance in the direction i and $(dyj)^{-1}\,du_y$ the same for the direction j, and $(dzk)^{-1}\,du_z$ the same for the direction k. The reduced expressions for these rates are $i\frac{du}{dx}$, $j\frac{du}{dy}$, $k\frac{du}{dz}$. Their sum

$$i\frac{du}{dx} + j\frac{du}{dy} + k\frac{du}{dz}$$

expresses the rate of growth of u in the direction of the most rapid growth.

Let ν denote that direction and n a distance along it, then

$$i\frac{du}{dx} + j\frac{du}{dy} + k\frac{du}{dz} = \nu\frac{du}{dn}.$$

The rate of growth of this quantity per unit of distance in the direction i is expressed by

$$(dxi)^{-1}\,d_x\left\{\frac{du}{dx}i + \frac{du}{dy}j + \frac{du}{dz}k\right\}$$

which, when reduced becomes

$$i\left(\frac{d^2u}{dx^2}i + \frac{d^2u}{dxdy}j + \frac{d^2u}{dxdz}k\right);$$

and similarly

$$j\left(\frac{d^2u}{dydx}i + \frac{d^2u}{dy^2}j + \frac{d^2u}{dydz}k\right)$$

and

$$k\left(\frac{d^2u}{dzdx}i + \frac{d^2u}{dzdy}j + \frac{d^2u}{dz^2}k\right).$$

As

$$\frac{d^2u}{dxdy} = \frac{d^2u}{dydx}$$

we obtain on multiplying and adding the scalar

$$\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}.$$

Thus,

$$i\frac{d}{dx} + j\frac{d}{dy} + k\frac{d}{dz}$$

and u combine the same as if the former were a simple vector, the latter being a scalar. The single symbol used to denote it is ∇. By treating ∇ as a quadrantal versor, Hamilton and Tait obtain

$$\nabla(\nabla u) = -\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}\right).$$

As ∇ cannot be the axis of a quadrantal version, it is not evident where the rotation comes in. By the ordinary rules of multiplication we get

$$\nabla^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2},$$

precisely equal to Laplace's operator.

The change of u for any other direction ρ is obtained by

$$\frac{d}{d\rho} = \frac{dx}{d\rho}\frac{d}{dx} + \frac{dy}{d\rho}\frac{d}{dy} + \frac{dz}{d\rho}\frac{d}{dz}.$$

Of a vector quantity.—Let

$$\mathbf{C} = ui + vj + wk$$

denote any vector quantity; then

$$\begin{aligned}\nabla\,\mathbf{C} &= (dxi)^{-1}\,d_x\mathbf{C} + (dyj)^{-1}\,d_y\mathbf{C} + (dzk)^{-1}\,d_z\mathbf{C}\\ &= i\left(\frac{du}{dx}i + \frac{dv}{dx}j + \frac{dw}{dx}k\right)\\ &\quad + j\left(\frac{du}{dy}i + \frac{dv}{dy}j + \frac{dw}{dy}k\right)\\ &\quad + k\left(\frac{du}{dz}i + \frac{dv}{dz}j + \frac{dw}{dz}k\right)\end{aligned}$$

from which scalars and vectors may be formed as on p. 112. By combining them simply we obtain

$$\nabla\mathbf{C} = \frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} + \left(\frac{dw}{dy} - \frac{dv}{dz}\right)i + \left(\frac{du}{dz} - \frac{dw}{dx}\right)j + \left(\frac{dv}{dx} - \frac{du}{dy}\right)k.$$

The scalar

$$\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}$$

may be denoted by $cos\,\nabla\mathbf{C}$, and the vector by $Sin\,\nabla\mathbf{C}$. If

$$cos\,\nabla\mathbf{C} = 0,$$

then $\mathbf{C}$ is said to be a *solenoidal* vector quantity; and if

$$Sin\,\nabla\mathbf{C} = 0,$$

then $\mathbf{C}$ is said to be an irrotational vector quantity.

Successive differentiation.—From the principle that

$$\nabla(\nabla u) = \frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2},$$

it follows that $\nabla(\nabla \mathbf{C})$ is not equal to $\nabla^2\mathbf{C}$. For

$$\begin{aligned}\nabla(\nabla\mathbf{C}) = &\left(i\frac{d}{dx}+j\frac{d}{dy}+k\frac{d}{dz}\right)\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)\\ &+\frac{d}{dx}\left(\frac{dw}{dy}-\frac{dv}{dz}\right)+\frac{d}{dy}\left(\frac{du}{dz}-\frac{dw}{dx}\right)+\frac{d}{dz}\left(\frac{dv}{dx}-\frac{du}{dy}\right)\\ &+\left\{\frac{d}{dy}\left(\frac{dv}{dx}-\frac{du}{dy}\right)-\frac{d}{dz}\left(\frac{du}{dz}-\frac{dw}{dx}\right)\right\}i\\ &+\left\{\frac{d}{dz}\left(\frac{dw}{dy}-\frac{dv}{dz}\right)-\frac{d}{dx}\left(\frac{dv}{dx}-\frac{du}{dy}\right)\right\}j\\ &+\left\{\frac{d}{dx}\left(\frac{du}{dz}-\frac{dw}{dx}\right)-\frac{d}{dy}\left(\frac{dw}{dy}-\frac{dv}{dz}\right)\right\}k.\end{aligned}$$

The scalar term vanishes and the term for i is

$$\begin{aligned}&\frac{d}{dx}\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)i+\left\{\frac{d^2v}{dxdy}+\frac{d^2w}{dxdz}-\left(\frac{d^2u}{dy^2}+\frac{d^2u}{dz^2}\right)\right\}i\\ &=2\frac{d}{dx}\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)i-\left(\frac{d^2u}{dx^2}+\frac{d^2u}{dy^2}+\frac{d^2u}{dz^2}\right)i.\end{aligned}$$

Hence

$$\begin{aligned}\nabla(\nabla\mathbf{C}) = &\,2\left(\frac{d}{dx}i+\frac{d}{dy}j+\frac{d}{dz}k\right)\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)\\ &-\left(\frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d^2}{dz^2}\right)(ui+vj+wk)\end{aligned}$$

The condition for $\nabla(\nabla\mathbf{C})$ being equal to $\nabla^2\mathbf{C}$ is $\nabla^2\mathbf{C} = \nabla\cos\nabla\mathbf{C}$. It is equal to $-\nabla^2\mathbf{C}$ if $\nabla\cos\nabla\mathbf{C} = 0$.

The following is another investigation. As the rules for ∇ are the same as those for a vector; we form the product

$$\left(\frac{d}{dx}i+\frac{d}{dy}j+\frac{d}{dz}k\right)\left(\frac{d}{dx}i+\frac{d}{dy}j+\frac{d}{dz}k\right)(ui+vj+wk)$$

by finding

$$\Sigma i^3+\Sigma i\,(ij)+\Sigma i\,(ji)+\Sigma i\,(jj)+\Sigma ijk.$$

Now

$$\Sigma i^3 = \frac{d^2u}{dx^2}i+\frac{d^2v}{dy^2}j+\frac{d^2w}{dz^2}k;$$

$$\Sigma i\,(ij) = -\left\{\left(\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}\right)j+\left(\frac{d^2w}{dy^2}+\frac{d^2w}{dz^2}\right)k+\left(\frac{d^2u}{dz^2}+\frac{d^2u}{dy^2}\right)i\right\}$$

$$\Sigma i\,(ji) = \left(\frac{d^2u}{dxdy}+\frac{d^2w}{dzdy}\right)j+\left(\frac{d^2v}{dydz}+\frac{d^2u}{dxdz}\right)k+\left(\frac{d^2w}{dzdx}+\frac{d^2v}{dydx}\right)i$$

$$\Sigma i\,(jj) = \left(\frac{d^2v}{dxdy}+\frac{d^2w}{dxdz}\right)i+\left(\frac{d^2w}{dydz}+\frac{d^2u}{dydx}\right)j+\left(\frac{d^2u}{dzdx}+\frac{d^2v}{dzdy}\right)k$$

Hence if we combine all the vectors

$$\begin{aligned}\nabla(\nabla\mathbf{C}) = &-\left(\frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d^2}{dz^2}\right)(ui+vj+wk)\\ &+2\left(\frac{d}{dx}i+\frac{d}{dy}j+\frac{d}{dz}k\right)\left(\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}\right)\end{aligned}$$

Examples of vector differentiation.

Let $\mathbf{R} = r\rho = xi+yj+zk;$

then

(1) $\nabla r = \nabla\sqrt{x^2+y^2+z^2} = \rho$

(2) $\nabla\mathbf{R}^2 = \nabla r^2 = 2\mathbf{R}$

(3) $\nabla r^n = nr^{n-1}\nabla r = nr^{n-1}\rho$

This is also true when n is negative, the most important case being $n = -1$; then $\nabla \frac{1}{r} = -\frac{1}{r^2}\rho$

(4) $\nabla \mathbf{R} = 3.$

(5) $\nabla \mathbf{R}^3 = \nabla (r^2\mathbf{R}) = (\nabla r^2)\,\mathbf{R} + r^2 \nabla \mathbf{R} = 5r^2$

(6) When n is odd, $\nabla \mathbf{R}^n = \nabla r^{n-1}\mathbf{R}$
$= (n-1)\, r^{n-2}\,\rho\,\mathbf{R} + 3r^{n-1} = (n+2)\, r^{n-1}$

(7) $\nabla (u\mathbf{C})$ is not in general $= \nabla (\mathbf{C}u)$
For $\nabla (u\mathbf{C}) = (\nabla u)\,\mathbf{C} + u\,(\nabla \mathbf{C})$
and $\nabla (\mathbf{C}u) = (\nabla \mathbf{C})\, u + \mathbf{C}\,(\nabla u)$;
but $(\nabla u)\,\mathbf{C}$ is not equal to $\mathbf{C}\,(\nabla u)$, unless $\mathbf{C}$ and ∇u have the same axis

(8) $\nabla \rho = \nabla \left(\frac{\mathbf{R}}{r}\right) = (\nabla \mathbf{R})\,\frac{1}{r} + \mathbf{R}\left(\nabla \frac{1}{r}\right) = \frac{3}{r} - \frac{1}{r} = \frac{2}{r}$

(9) $\nabla (Sin\, \mathbf{AR}) = \nabla (\mathbf{AR}) - \nabla cos\, \mathbf{AR} = 2\mathbf{A}.$

(10) To prove that $\nabla (\nabla \frac{1}{r}) = 0.$ Since $\nabla \frac{1}{r} = -\frac{1}{r^2}\rho$
$\nabla (\nabla \frac{1}{r}) = 2\frac{1}{r^3}\rho^2 - \frac{1}{r^2}\nabla \rho = 0.$

(11) $\nabla (\nabla \mathbf{R}^2) = \nabla\, 2\mathbf{R} = 3 \cdot 2 = 6$

(12) $\nabla\, (\nabla\, (\nabla \mathbf{R}^3)\,) = 5 \cdot 2 \cdot 3 = 30$

(13) $\nabla^4 \mathbf{R}^4 = 4 \cdot 5 \cdot 2 \cdot 3 = 120.$

GENERALIZED ADDITION.

Signless quantities at different points.— Given a mass m, at $\mathbf{A}_1$ and m_2 at $\mathbf{A}_2$; by adding them is meant adding the masses, and finding such a position that the mass-vector of the sum of the masses will be equal to the sum of the mass-vectors. Let m times the vector $\mathbf{A}_1$, be $\mathbf{P}$, and m_2 times the vector $\mathbf{A}_2$ be $\mathbf{Q}$; the resultant $\mathbf{R}$ is the sum of the mass-vectors; take $\mathbf{S}$ equal to $\mathbf{R}$ divided by $m_1 + m_2$ (fig. 22).

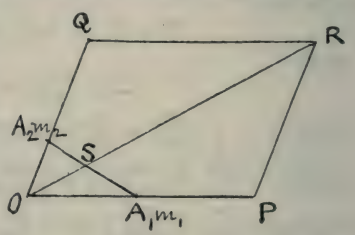

FIG. 22.

Hence $\mathbf{A}_1 \cdot m_1 + \mathbf{A}_2 \cdot m_2 = \frac{m_1\mathbf{A}_1 + m_2\mathbf{A}_2}{m_1 + m_2} \cdot (m_1 + m_2).$

This is generalized addition; for if we put $\mathbf{A}_2 = \mathbf{A}_1$, we get ordinary addition.

Scalar quantities at different points. — The same principle applies to a quantity which may be positive or negative; but there is a special case when the quantities are equal and of opposite sign. Then

$$\mathbf{A}_1 \cdot m - \mathbf{A}_2 \cdot m = \frac{m\mathbf{A}_1 - m\mathbf{A}_2}{m - m} \cdot (m - m)$$
$$= m\,(\mathbf{A}_1 - \mathbf{A}_2)$$

Their sum is then a moment, as in the case of a magnet.

Parallel vector quantities at different points.—If the vector quantities have the same axis, they are added in the same manner as signless quantities; hence (fig. 23).

$$\mathbf{A}_1 \cdot \mathbf{B}_1 + \mathbf{A}_2 \cdot \mathbf{B}_2 = \frac{b_1\mathbf{A}_1 + b_2\mathbf{A}_2}{b_1 + b_2} \cdot (b_1 + b_2)\,\beta$$

If they have opposite axes, they are added like scalar quantities. Suppose $\mathbf{B}_1 = b_1\beta$ and $\mathbf{B}_2 = b_2\,(-\beta)$; then

$$\mathbf{A}_1 \cdot \mathbf{B}_1 + \mathbf{A}_2 \cdot \mathbf{B}_2 = \frac{b_1\mathbf{A}_1 - b_2\mathbf{A}_2}{b_1 - b_2} \cdot (b_1 - b_2)\,\beta.$$

If further $b_1 = b_2$, then their sum is

$= \mathbf{A}_1\mathbf{B} - \mathbf{A}_2\mathbf{B} = (\mathbf{A}_1 - \mathbf{A}_2)\,\mathbf{B}$ $= \mathit{cos}\,(\mathbf{A}_1 - \mathbf{A}_2)\mathbf{B} + \mathit{Sin}\,(\mathbf{A}_1 - \mathbf{A}_2)\mathbf{B}$.

The latter term is the moment of a couple.

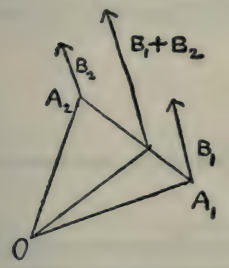

FIG. 23.

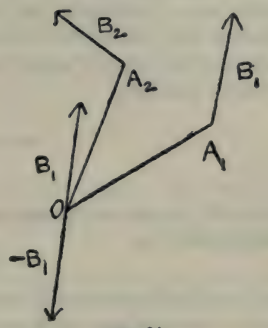

FIG. 24.

Vector quantities at different points.—The following is the most general form of the principle that a quantity is not changed by the simultaneous addition and subtraction of the same quantity (fig. 24).

$$\begin{aligned}\mathbf{A}_1 \cdot \mathbf{B}_1 &= 0 \cdot \mathbf{B}_1 - 0 \cdot \mathbf{B}_1 + \mathbf{A}_1 \cdot \mathbf{B}_1 \\ &= 0 \cdot \mathbf{B}_1 + \mathbf{A}_1\mathbf{B}_1\end{aligned}$$

Hence

$$\begin{aligned}\mathbf{A}_1 \cdot \mathbf{B}_1 + \mathbf{A}_2 \cdot \mathbf{B}_2 &= 0 \cdot (\mathbf{B}_1 + \mathbf{B}_2) + \mathbf{A}_1\mathbf{B}_1 + \mathbf{A}_2\mathbf{B}_2 \\ &= 0 \cdot (\mathbf{B}_1 + \mathbf{B}_2) + \mathit{cos}\,\mathbf{A}_1\mathbf{B}_1 + \mathit{cos}\,\mathbf{A}_2\mathbf{B}_2 \\ &\quad + \mathit{Sin}\,\mathbf{A}_1\mathbf{B}_1 + \mathit{Sin}\,\mathbf{A}_2\mathbf{B}_2\end{aligned}$$

And generally $\Sigma\,\mathbf{A} \cdot \mathbf{B} = 0 \cdot \Sigma\,\mathbf{B} + \Sigma\,\mathit{Sin}\,\mathbf{AB} + \Sigma\,\mathit{cos}\,\mathbf{AB}$.

ON CERTAIN SPACE AND SURFACE INTEGRALS. By Dr. THOMAS S. FISKE, Columbia College, New York, N. Y.

[ABSTRACT.]

THE extension to space of certain results obtained by Prof. B. O. Peirce in the Proceedings of the American Academy of Arts and Sciences for May, 1891. A formula in generalized coördinates was deduced giving the expression for a space integral in terms of a surface integral, and applications were made to the special cases of polar and cylindrical coördinates.

[The paper is printed in full in the *Annals of Mathematics*, Vol. VI, p. 61.]

ON A DIGEST OF THE LITERATURE OF THE MATHEMATICAL SCIENCES. By ALEX. S. CHRISTIE, U. S. Coast and Geodetic Survey, Washington, D. C.

[ABSTRACT.]

THE author suggests the formation of a digest consisting of say one hundred volumes: (1) containing everything of value hitherto done in the mathematical sciences; (2) logically and perspicuously arranged; (3) in a homogeneous terminology and notation; (4) each distinctive truth or method referred to its discoverer; and (5) the whole thoroughly indexed; that mathematicians, astronomers and physicists throughout the world be invited to aid in its preparation; that the coöperation of the B. A. A. S. be secured by this Association, if possible, and the work done under the joint and coördinate direction of the two kindred associations; that the digest be prepared and published in the English language; and that all nations be accorded the right to issue the same in their respective languages at their proper expense.

LATITUDE OF THE SAYRE OBSERVATORY. By Prof. C. L. DOOLITTLE, South Bethlehem, Pa.

[ABSTRACT.]

THIS paper gives the results obtained from the discussion of 1142 Zenith Telescope observations made at different times during the interval 1876–90.

Five different determinations of the latitude were made as follows:

1876.47	$\varphi = 40^\circ\ 36'\ 23''.632 \pm .054$	141 observations.
1877.55	$40\ 36\ 24''.076 \pm .042$	190 "
1886.14	$40\ 36\ 23''.484 \pm .044$	280 "
1888.70	$40\ 36\ 23''.044 \pm .072$	121 "
1890.47	$40\ 36\ 23''.396 \pm .024$	410 "

In order to determine to what extent the apparent change in the value of φ might be due to periodic fluctuations a series of 344 equations was formed by combining results of observations made during short intervals. The following general expression for the latitude at any time τ reckoned from 1890.0 being assumed.

$$\varphi = \varphi' + x + \tau y + r \sin (R + m\tau) + \rho \sin (\xi + \mu\tau)$$

m representing the motion of the earth's axis in a period of one year.

μ representing the motion of the earth's axis in a period of 10 months.

The result is as follows:

$40^\circ\ 36'\ 23''.294 - .0355\ \tau + ''.325 \sin (268^\circ.9 + 360\tau) + ''.118 \sin (29^\circ.3 + 431.4\tau)$.

Assuming an annual period only we have:

$$40^\circ\ 36'\ 23.''305 - .0377\ \tau + .''228 \sin (271^\circ.7 + 360\tau).$$

Assuming a ten-month period only,

$$40^\circ\ 36'\ 23.''361 - .0432\tau + ''.114 \sin (256^\circ.8 + 431.4\tau).$$

Assuming the period to be that of the right ascensions of the stars,

$$40^\circ\ 36'\ 23''.304 - .0406\tau + ''.181\ \sin\ (178^\circ.1 + \alpha).$$

Assuming the change to be purely secular,

$$40^\circ\ 36'\ 23''\ 394 - .0402\tau.$$

There seems to be a clearly marked secular diminution of about 0″ 04 annually, but the observations are not as a whole well distributed for determining the periodic terms. The latter have been determined from those pairs observed during the year, 1890. Using only those which were observed both morning and evening in order to make the result independent of the places of the stars:

232 observations upon 14 pairs were available, giving,

$$\Delta\varphi = ''.228\ \sin\ (306^\circ.5 + 360\tau)$$

This is only a preliminary determination, a more complete examination of this term will be undertaken later.

[This paper will be published more fully in the *Astronomische Nachrechten.*]

THE SECULAR VARIATION OF TERRESTRIAL LATITUDES. By Prof. GEORGE C. COMSTOCK, Washburn Observatory, Madison, Wis.

[ABSTRACT.]

THE purpose of this paper is to show from existing astronomical data that the terrestrial pole is in motion and that the amount and direction of this motion admit of at least approximate determination.

The data available for this purpose are the following observed annual variations of the latitude:

Pulkowa	−0″.005
Königsberg	−0.003
Washington	+0.042
Madison	+0.043

From which it results that the north pole is moving along the meridian 69° west of Greenwich at the rate of 4″.5 per century.

The paper contains further a program for the better determination of the elements of this motion.

[Published in full in *Am. Jour. Sci.*, Nov., Dec., 1891.]

STANDARDIZING PHOTOGRAPHIC FILMS WITHOUT THE USE OF A STANDARD LIGHT. By Prof. FRANK H. BIGELOW, Nautical Almanac Office, Washington, D. C.

[ABSTRACT.]

THE application of photography to absolute photometric measures has been a failure on account of uncontrollable variations in the standard light, in the areas of the film on the same plate, and because of our ignorance of the fundamental law connecting the density of the deposit with the time of the exposure.

The experiments of the astronomers of the Lick Observatory illus trate conclusively that the variations are such as to make the practical application of photography to measures of the actinic brightness of the corona nearly worthless.

It has generally been supposed that the density was simply proportional to the times, but molecular considerations and actual measures show that this conception cannot be true. The probability is that the deposit is a logarithmic function of the time of exposure.

The following law and solution for the problem are therefore proposed:

Let F_1 = the initial energy, or the number of undeposited molecules of silver.

Let F = the energy, or the undeposited molecules after the interval t.

Let m = the modulus of the logarithmic system.

$\frac{dF}{dt} = -mF$, at any instant of time, $F = F_1 e^{-mt}$, the energy after the time t.

The two intervals t' and t'' give,

$$log\ F' = log\ F_1 - m\,t'$$
$$log\ F'' = log\ F_1 - m\,t''$$
$$m = \frac{log\ F' - log\ F''}{t'' - t'} = \frac{1}{n}$$

The significance of n can be seen by comparing this equation with the equation of the logarithmic curve, $y = ae^{\frac{x}{n}}$ where $a = F_1$ is the intercept on the axis y, n the constant subtangent. Properly on account of the system being one of decay the curve must be developed towards the left, where it approaches the axis x.

If $y = F'$, F'', etc., denotes the density, $x = t'$, t'', etc., denotes the times we compute $m = \frac{1}{n}$.

Each plate may be said to have a curve which defines its sensitiveness, and it is only required to locate two points on it in order to determine the curve.

Hence practically if *any light* is used, and exposures are made for two different intervals, we have two characteristic points of density. It only remains to note accurately the intervals, and to compare the densities with a *standard scale of density*, numbered from 100 before exposure to 0 at the maximum density when the reversal of color sets in. The formation of a uniformly graduated scale in black and white will be a difficult work of art, but it ought to be undertaken as soon as possible for use in this connection.

EXHIBITION AND DESCRIPTION OF A NEW SCIENTIFIC INSTRUMENT, THE AURORA-INCLINOMETER. By Prof. FRANK H. BIGELOW, Nautical Almanac Office, Washington, D. C.

[ABSTRACT.]

THIS instrument was designed by the author and constructed by the

U. S. Coast and Geodetic Survey. Its purpose is to measure the inclination of the streamers of the Aurora with reference to a vertical plane passing through the zenith and the horizon points of the base of the ray. The measures are used in the author's theory of the Aurora, published in the American Journal of Science, February, 1891.

METHOD OF CONTROLLING A DRIVING CLOCK. By F. P. LEAVENWORTH, Haverford College, Pa.

[ABSTRACT.]

1. A BRASS ring is substituted for hook in the Clarke governor of Equatorial. The foot which struck the hook now strikes the inside of ring continually.

2. An armature placed at top of spindle is controlled by an electric magnet operated by a common office clock which beats once to two revolutions of the governor.

ANNALS OF MATHEMATICS. By WM. E. HEAL, Marion, Indiana.

[ABSTRACT.]

THIS paper is a continuance and completion of a paper published in the Annals of Mathematics for October, 1889, on the "Bitangential of the Quintic."

The final result is that the bitangential of the quintic is

$$1200\ \binom{\theta}{\theta} - 62025\ \theta\ \phi^2 + 87120\ \theta\ \binom{\phi}{H} - 140360\ \theta\ \binom{\phi'}{H} + 15000\ \phi\ \binom{\theta}{H} + H\left[81675\ \phi^3 - 15675\ \theta\ \phi - 35640\ \binom{\theta}{\phi} + 54720\ \binom{\theta}{\phi'} - 222750\ \phi\ \binom{\phi}{H} + 342000\ \phi\ \binom{\phi'}{H}\right] + H^2\left[264627\ \binom{\phi}{\phi} - 812592\ \binom{\phi}{\phi'} + 623808\ \binom{\phi'}{\phi'}\right] = 0.$$

FLUCTUATING STARS. By HENRY M. PARKHURST, New York, N. Y.

[ABSTRACT.]

THE author proposed to distinguish between known variable stars and fluctuating stars, which yield inconsistent results too great to be probably attributable to errors of observation, and yet so uncertain and so small a variation as not to suggest special watching. A large majority of the stars fluctuate so much that it is only in exceptional cases that photomet-

ric measures are entirely satisfactory. Yet if four per cent of the stars are regarded as fluctuating and excluded from use as photometric standards, the remainder may be regarded as permanent. From an examination of the results in the meridian photometer observations of the Harvard Observatory and also of the results in the photographic catalogue of the same observatory, he had found there were no appreciable differences of a progressive or periodic character, as affecting the principal number of the stars. The marked discordances attending the few fluctuating stars, in view of the counterbalancing character of most of their changes and of most of the fluctuations of other stars whose changes are insufficient to require placing them in this class, do not appreciably increase the probable error of a standard with the lapse of time.

TABULATION OF LIGHT-CURVES. By HENRY M. PARKHURST, New York, N. Y.

[ABSTRACT.]

THE author proposed a system of lettering comparison stars so as to indicate their magnitudes and showed its usefulness in the tabulation of light-curves and in the determination of the maxima of variable stars.

PARALLAX OF α LEONIS. By PROF. JEFFERSON G. KESHNER, Lancaster, Pa.

[ABSTRACT.]

1. A short account of the eleven inch Clark-Repsold equatorial and the micrometer with which these observations were made.

2. An account of the way in which the observations were made, taking account of a temperature correction in the reductions and use of the focal scale.

3. The parallax of α Leonis is $0''{,}170 \pm 0{,}045$.

THE FUNDAMENTAL LAW OF ELECTRO-MAGNETISM. By Prof. J. LOUDON, University of Toronto, Canada.

ON THE LONG PERIOD TERMS IN THE MOTION OF HYPERION. By Prof. ORMOND STONE, Director of Lander McCormick Observatory, University of Virginia, Va.

THE ZODIACAL LIGHT AS RELATED TO TERRESTRIAL TEMPERATURE VARIATION. By O. T. SHERMAN, Cambridge, Mass.

GROUPS OF STARS, BINARY AND MULTIPLE. By G. W. HOLLEY, Ithaca, N. Y.

NOTE ON SOME RECENT PHOTOGRAPHS OF THE REVERSAL OF THE HYDROGEN LINES OF SOLAR PROMINENCES. By J. A. BRASHEAR, Allegheny, Pa.

DESCRIPTION OF THE GREAT SPECTROSCOPE AND SPECTROGRAPH CONSTRUCTED FOR HALSTEAD OBSERVATORY, PRINCETON, N. J. By J. A. BRASHEAR, Allegheny, Pa.

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ADDRESS

BY

FRANCIS E. NIPHER,

VICE-PRESIDENT, SECTION B.

THE ETHER.

It was with some fear and trembling that I selected as the subject of a brief address, a subject of such vast dimensions; and the feeling increased as it became more and more evident how difficult it is to give clear expression to ideas that are very far from clear.

In former days many reasons were given showing the necessity for the existence of an ether which do not seem conclusive now. We can scarcely appreciate the bearing of an argument to the effect that there must be an ether or Nature would be disgusted with the major portion of space. We should begin at once to wonder what there could have been in the experience or training of any person that could lead him to such a conclusion. We do not see the need of an ether to hold up the stars and planets and prevent them from falling to the ground. We do not try to explain by similar means how the planets are kept in motion.

We do, however, have other needs for an ether which seem important and pressing; still we can not help wondering occasionally with Theophrastus Such what kind of hornpipe we are dancing now. How will our ideas commend themselves to those who follow.

For fifty years it was taught that the luminiferous ether was an incompressible jelly-like mass, and that light was an elastic pulsation in this medium. The elastic theory, however, was burdened with serious difficulty. No phenomena corresponding to a vibration normal to the wave front could be found, but mathe-

matical analysis showed that such waves should in general exist in an elastic medium. Green saw that this wave would produce no optical phenomena if its velocity were either zero or infinite, and concluded that it could not be zero in a stable medium. Those who followed him in time also accepted his conclusion that the ether was incompressible, and that the compression-rarefaction wave must travel with an infinite speed. So the matter stood until 1865 when Maxwell proposed an electro-magnetic theory of light. According to this theory of light no compression-rarefaction wave should exist, and light was conceived to consist of local electrical displacement in a plane at right angles to the line of propagation.

The rival theory met with great favor. It gradually became clear that Maxwell's electric theory of light was attended with less difficulty than the elastic theory. Twenty-three years later, Sir William Thomson brings a powerful reinforcement to the elastic theory which changes the whole aspect of the case. He simply suggests that the compression-rarefaction wave could properly and logically be gotten rid of in the elastic theory by making its velocity zero, instead of infinite as Green had done in 1828. What Thomson did was to examine anew the ground upon which Green had concluded that a zero velocity for the compression wave involved an unstable state of the medium, and it was found that such a conclusion did not follow.

And it is worthy of remark, as a matter of congratulation showing how far scientific men have emerged from the intellectual pugilism of last century, that this audacious departure was met with pleased surprise, instead of angry polemics against a new heresy.

The modern theory of the ether took its origin with the undulatory theory of light. It had for a tangible basis the observed fact that light requires time for its transmission. Whether measured over long distances through interplanetary spaces, or through short distances on the surface of the earth, the time required for transmission is proportionate to the distance. It was to such facts that men finally came to look for a justification of the assumption of an all pervading medium. The modern theories of the nature of the ether are based wholly on the results which must be produced by this invisible machinery, instead of upon an assumed dictum that Nature abhors a vacuum. Perhaps no teaching of science is now more firmly established than the doctrine of the existence of an ether, and that it is capable of transmitting energy by virtue of

peculiarities which must be as definite as those which characterize a train of cog-wheels.

But when one comes to assemble all of the results which remain to be accounted for and explained, it becomes exceedingly difficult to construct a mental image in three-dimensional space of the machinery capable of producing them all.

Green's idea of the ether makes it an incompressible, frictionless, structureless jelly, sometimes called a "solid," which opens out and allows the particles of ordinary matter to sweep through without appreciable resistance. Thomas Young likened the operation to the sweeping of the wind through the leaves and branches of a forest. Certain well-known electrical experiments of Faraday and Cavendish seem to require the assumption that electricity is, or is some function of, an incompressible medium. On the other hand, the slowing up of light in space occupied by matter indicates that the ether within must be either more dense (as Fresnel believed) or less elastic than that existing in free space. It is certainly very difficult to understand what there can be in the molecules of matter which can increase the density of an incompressible medium as the experiments of Fresnel seemed to require; nor is it as yet easy on any hypothesis to account for those condensed films of bound ether which are carried along with the particles of moving matter. They seem to be differentiated with equal sharpness from the free ether which sweeps through matter, and from the spinning aggregations of ether vortices which Thomson assumes may perhaps make up the molecule or the atom. Certainly it would seem that a vortex ring in a medium so devoid of friction that these vortices are permanent, could hardly drag along with it portions of the surrounding medium from which the analysis of Helmholtz shows it must be wholly and forever differentiated. And the matter is not simplified by the beautiful experiment of Michelson and Morley. It appears that the frictionless ether even adheres in a layer around the earth as a whole, or at least that it was entangled in and carried along with the matter composing the building in which their experiments were made.

If, however, one forms a Torricellian vacuum in a barometer tube of either transparent or opaque material, it is easily and completely shown by an inclination of the tube, that the ether flows freely through matter. Whether the ether be incompressible or highly compressible it seems to be as impossible to compress it in a

chamber surrounded by matter, as it would be to compress water or air in a fisher's net. The fact that a rotational phenomenon, such as must exist in the field of a steel magnet, is maintained indefinitely without the expenditure of energy, must certainly justify the assumption that the ether is frictionless, that the ether-vortex atom is a possibility.

The effects which seem to be nearest to a mechanical explanation are those which result in heat or light and electrical and magnetic induction. It is possible to construct machinery which will represent the conditions for propagation of a magnetic induction in a plane radial to a conducting wire. A train of cog-wheels separated by elastic idle-wheels which articulate with them, or a series of smooth-rimmed fly wheels connected by elastic bands, will do the work. It becomes more difficult when we spread this paraphernalia into three-dimensional space.

No one of course thinks of the geared ether models of Maxwell and Fitzgerald as anything more than an aid to a conception of the nature of the action to be explained. When we come down to the working drawings we find great room for conjecture, and some demands for invention. Do the particular cog-wheels which slip on each other without friction at the surface and within the body of a perfect conductor, ever get outside of the body into free space where they must gear rigidly with each other? If so why do they behave so differently in the two places? What happens to this gearing when masses of matter which it permeates are set into rotation? What happens when a steel magnet is set to spinning on its own axis? Is there a shearing of the field at the surface, or can the moment of a magnet be varied by such a rotation? Is there any relation between the earth's magnetism and the motion of masses of ether at the earth's surface? It is exceedingly difficult to understand how a frictionless medium in which a magnetic spin is permanent can offer resistance to shear, unless the rigidity involved is due to motion.

Another function which the ether should perform is the transmission of gravitation. The theory which has attracted most attention, the only one suggested which has been seriously considered, is the one first announced by Le Sage of Geneva, and elaborated by Preston and others. It seems to require that the ether shall partake of the nature of a gas, the mean free path being of interplanetary dimensions. Such a medium it is not difficult to admit

as a possibility. The theory accounts for the gravitation of bodies towards each other as due to a difference in the bombardment of bodies on the exposed and sheltered sides. Each body shields the other so that gravitating bodies are pushed together. It is, however, necessary that the particles at the centre of the earth shall have the same resultant differential pressure directly exerted upon them, causing them to gravitate towards the sun, as if the surrounding mass of the earth were removed. It is in fact necessary to assume that nearly all the ether particles which plunge into the earth's figure pass straight through the earth without encounter with matter.

It is, however, of some interest, to know quantitatively about what velocities must be involved in such an impact theory for gravitation. DeVolson Wood has made a computation of the density of an elastic medium capable of transmitting a pulsation with the velocity of light, and of transmitting from the sun to the earth 2.8 calories per minute per square centimeter of surface. While it seems to me that some fault may be found with his analysis, still the results reached by him seem to be of the proper order of magnitude.

The density of the ether turns out to be about 2.6×10^{-24} lbs. per cubic foot so that a mass equal in volume to that of the earth would contain about one and seven-tenths of a pound. This value for density lies well within the limits which Sir William Thomson assigned to the same quantity.

Suppose a stream of ether of such material should sweep radially sunward, its particles colliding in unelastic impact with the earth, what velocity must be given to this current in order that the earth might be kept in its present orbit? The velocity turns out to be eight millions of times the velocity of light. The mass of ether colliding per second would be 14,000 tons, which is equal to the mass of a sphere of water having a radius of about fifty feet.

But in Le Sage's hypothesis the ether particles do not move in parallel stream lines. They plunge into the earth on all sides, the sheltering effect of each gravitating body upon the other being the cause of gravitation. But this sheltering effect is very small, by reason of the open structure which matter must be assumed to have in order that the interior particles of large masses may be accessible to direct impact. It follows that the percentage of particles really effective in producing gravitation must be very small. Likewise that the velocities of individual particles must enormously ex-

ceed the velocity computed for a stream of ether sweeping radially sunward and capable of holding the earth in its orbit.

It is unphilosophical to condemn the theory of Le Sage because it requires us to deal with such immense velocities. Any theory of gravitation must involve something unusual, and it has been pointed out that the velocity of gravitation must enormously exceed that of light. But there are other difficulties.

The rebound of the corpuscles must be in perfectly elastic collision. Otherwise the bombarded body will rise in temperature. By reason of the open structure assumed and necessary, in order that the effective surface may be proportional to mass, the exterior figure is of no importance. For simplicity of conception, if we assume a solitary sphere in space, it will be symmetrically beaten from all sides. The particles which pass straight through without deflection, or elastic rebound, will be symmetrical all around, as will likewise the few which suffer reflection. A second body now appearing in its field, will indeed shield the first by deflecting particles which would otherwise strike it, but will reflect to the body an equal number which would otherwise not strike it, the latter group having the same average momentum as the former.

Sir William Thomson has suggested that this difficulty may be avoided by assuming that the collision is not a perfectly elastic one, and that the rise in temperature may be prevented by rotation of the colliding particles. This might be true of the ether particles, but there is the best of reason for believing that there is no molecular rotation in solid bodies.

It seems probable, therefore, that a rebound sufficiently unelastic to account for gravitation, must result in a rise in temperature, which can scarcely be admitted. The theory has, however, been defended with great skill by Preston, who has attempted to show that such a medium may even produce the transverse vibrations of light. The objection that gravitation must travel at enormously greater speed than light he tries to meet by the hypothesis that the gaseous ether may have two groups or particles, one much larger than the other. The properties of the luminiferous ether have, however, been so well worked out in the last four or five years, that it seems hardly probable that a gaseous ether can be admitted as the medium which transmits light. Whether gravitation can or cannot be explained in some such way as Le Sage suggested, it seems very well worthy of question whether the gravitation medium

can be the ether which transmits radiant energy with a velocity of 300,000,000 of meters per second. Sir William Thomson's last word on the elastic solid theory of ether, according to which the compression wave is impossible by reason of a property which is imparted to the medium, seems to cut off the last hope that an elastic solid luminiferous ether can be concerned in gravitation. The electric theory of light does not require Sir William Thomson's limitation to be put upon the medium. According to this theory the medium may be incompressible, and there is strong reason to believe that it is practically so. As Willard Gibbs has pointed out, the two theories seem to be practically on a common footing if the third wave is given an infinite velocity in the electric theory, and zero velocity in the elastic solid theory.

There are other points concerning the action of matter upon the ether, which are perhaps in a fair way to receive a clearer solution. The observed fact that light travels in water with a speed of about three-fourths of what it has in air, apparently means that the transmitting medium is either more dense or less rigid in water than in air. Fresnel's hypothesis is that its rigidity is the same in the two media. His formula, as developed by Eisenlohr, for the relative motion of ether and matter which it permeates, when the matter is set into motion, assumes clearly and baldly that the ether is more dense inside of matter than in free space. The amount of ether occupying a volume of one cubic centimeter in air will condense to nine-sixteenths of a cubic centimeter on passing into water. It is compressed until its density is nearly doubled. To be more accurate, its density increases by seven-ninths of itself upon passing into water. Of course this is to be regarded as a mathematical fiction serving to bridge over a gap in our knowledge of the physics of the ether. Certainly a medium behaving in this manner could not be considered to be a shining success as an incompressible medium. Fresnel's conclusion rests mainly on an experiment first made by him and repeated with great success in an improved form by Michelson and Morley. This experiment was to determine the effect of moving water upon the velocity of light transmitted along its stream-lines. The result reached was that the resultant velocity of light is its velocity in the quiescent liquid plus or minus seven-sixteenths of the velocity of the moving liquid. The velocity of the water current was varied between 8.72 meters and 5.67 meters per second in Michelson and Morley's experiment.

A series was made with an intermediate velocity of 7.65 meters per second. The weights of the three determinations are quite different and it appears to me to be still an open question whether the result obtained is independent of the velocity of the water. In Eisenlohr's analysis he assumes a prism of matter moving bodily through a mass of quiescent ether. In Michelson and Morley's experiment the water was fed from an upper into a lower tank, passing on its way, through the experimental tubes. The conditions of the two experiments do not seem to be necessarily the same. The bounding surface between air and water is moving with a very small velocity in the apparatus of Michelson and Morley, and the observations are made through a fixed region in space. It is not clear that this difference is of importance, but it seems possible that it may be in determining the effects for different velocities.

The close agreement between the observed value of the velocity coëfficient for the moving ether and the value computed on the assumption of an actual condensation of the ether is, of course, a very weighty consideration. Still it seems very improbable that such a condensation can really take place. The ether may lag behind the moving water without any condensation, and other phenomenon requiring a greater density of ether in matter that exists in free space may, perhaps, receive other explanations that do less violence to our ideas of mechanics. Ether, in which the complex molecules of matter are entangled, certainly might act as if it were more dense without being really so.

What the experiment of Michelson and Morley seems to show is that the ether is swept along by the water, but lags behind. The question of density appears to me to be still an open one. Maxwell's experiment with a prism which was, as was then supposed, moving through ether at a speed of 18.6 miles per second, seems to have a very different relation to Fresnel's theory if the ether at the earth's surface is moving with it.

It does not seem hopeless to repeat the experiment of Michelson and Morley on a railway coach with water, or perhaps carbon bisulphide, at rest in the tube, if the road-bed and car selected are of the best construction and the apparatus is elastically supported. It would be necessary, probably, to rigidly connect the observer's seat and water-tube, and to support them with the observer by helical steel springs surrounded by rubber tubes filled with glycerine to dampen the vibrations. A speed of forty miles per hour will more than

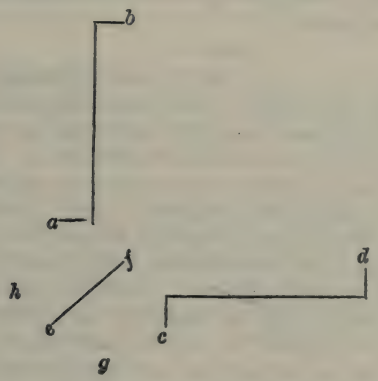
compensate for the suppression of one water column which will be replaced by air. This is precisely the form of experiment upon which Eisenlohr's analysis is based. In this form the conditions of the experiment are capable of great variation. The car becomes really the moving body, and the transparent region within through which the light passes may be shielded by any kind of opaque matter. Whatever the results may be they can hardly fail to add greatly to our knowledge of the effect of moving masses upon the luminiferous ether.

PAPERS READ.

A NEW METHOD FOR MEASURING THE EXPANSION OF SOLIDS. By Prof. EDWARD W. MORLEY, 749 Republic street, Cleveland, Ohio.

[ABSTRACT.]

AT the Toronto meeting of the Association, I described the application to a certain purpose of an apparatus which I had devised for the measurement of expansions of solid bodies. The method depends on the use of interference phenomena in monochromatic, and also in white, light, as produced in Michelson's intereferential refractometer. Let *a b* be the bar



whose expansion is to be measured. Place a bar *c d*, of nearly the same length, so that the eye at *g* sees *a b* coincide with the image of *c d*. Apply plane mirrors to the ends of the two bars, perpendicular to the axes of the bars. When adjustments are made, if a monochomatic light is placed at *h*, the observer at *g* will see interference phenomena produced by the light reflected from *b* and *d*, and also by that from *a* and *c*. If now a source of white light is placed at *h*, colored interference fringes will be seen at *a* when *a* and *c* are equidistant from a point arbitrarily selected in *e f*, and at *b*, when *b* and *d* are equidistant from a similar point. The difference in length of *a b* and *c d* can be measured by measuring the displacement of one of the bars, in the direction of its axis, which is required to show the two sets of interference bands at the two sets of surfaces. If now this

difference be determined while $c\ d$ is kept at a constant temperature, and that of $a\ b$ is changed, the absolute expansion of $a\ b$ is determined.

There are several ways of measuring the displacement needed to go from one set of fringes to the other. One way is to count the wave lengths of some monochromatic light in this distance. With proper apparatus, this is very easy and very accurate. Another is to prepare a measure of length consisting of two plane mirrors held at the proper distance, to compare the difference in length of the two bars with this measure by counting a few wave lengths, and then to count the larger number in the whole measure under favorable circumstances. This is as accurate as the first method, but needs means of exquisite adjustment. A third method consists in reading by scale and micrometer the displacement produced.

The merit of the method is that it permits the application of the wonderful accuracy of interferential methods to bars of any length.

MEASUREMENT OF THE EXPANSION OF JESSOP'S STEEL BY A NEW METHOD. By Prof. EDWARD W. MORLEY, Cleveland, Ohio, and Prof. WILLIAM A. ROGERS, Waterville, Me.

[ABSTRACT.]

AN apparatus has been set up in the Physical Laboratory of Colby University with which we have made a preliminary experiment by means of a new method. At the centre of the apparatus stands the diagonal mirror of an interferential refractometer devised by Michelson. Radiating from this at right angles are two slides, one of which is provided with a smooth and delicate motion by means of a screw and wedge. On each was placed a bar in an envelope for securing a constant temperature. Each bar was fitted with mirrors placed as described in a recent paper by one of us.

Both bars were surrounded with ice. After some hours, interferences in white light were produced at the nearer ends of the bars, and a microscope attached to the apparatus was set on a scale attached to one of the sliders. Then by the screw and wedge this slider, with the scale and bar, was moved in the direction of its length till interferences in white light were seen at the distant mirrors, and the scale was read. Five such measurements of the difference of length of the two bars were made (in say ten minutes) and the temperature was noted. This measurement having been repeated at intervals, one bar was surrounded by steam, and precisely similar measurements were made. The difference between the measurements with both bars in ice, and with one bar in steam is obviously the expansion of the bar whose temperature had been varied.

When the method used was first explained in public some years ago, it was stated that it would be almost necessary to place the bars in a vacuum. In this preliminary experiment, we spared the expense of so doing. We prevented the deposition of moisture on the cold mirrors by introducing a current of dry air, submitted to the distortion and unsteadiness of the in-

terference fringes due to currents of air in the hot or cold envelopes of the bars, and made a numerical correction for the change in the refraction of the air. Not being prepared to measure the temperature of the bars, we have not determined the coëfficient of expansion of the steel bar used, but we have determined its actual expansion between the two temperatures, we have satisfied ourselves that the method will be convenient and valuable in practice, and we have proved that it will give concordant results. We give, to show the concordance of results, the comparisons when one bar was in steam, as the vibration caused by the jet of steam was unfavorable to ease and accuracy of observation and these results were therefore the less concordant.

Aug. 5, 1.20 P. M. Turned on steam around steel bar. (Bronze bar in ice since Aug. 3, at 6.30 P. M.)

2.45 to 3.05 P. M. Readings, 1.0600, 1.0600, 1.0595, 1.0595, 1.0597; mean, 1.0597.

3.40 to 4.00 P. M. Readings, 1.0610, 1.0600, 1.0610, 1.0611, 1.0611; mean, 1.0608.

4.30 to 4.45 P. M. Readings, 1.0613, 1.0610, 1.0613, 1.0601, 1.0604; mean, 1.0608.

4.45 P. M. Turned on all steam; 12 lbs. at boiler.

5.30 to 5.45 P. M. Readings, 1.0613, 1.0616, 1.0618, 1.0616, 1.0619; mean, 1.0616.

5.45 P. M. Turned off part of steam.

7.30 P. M. Ice melted away somewhat around bronze bar.

7.30 to 7.50 P. M. Readings, 1.0606, 1.0600, 1.0602; mean, 1.0603.

8.40 to 8.55 P. M. Readings, 1.0604, 1.0604, 1.0590, 1.0590, 1.0595; mean, 1.0599.

The mean error of a determination was therefore .0006^{mm}, which includes not only the error due to the interferential apparatus, but to the microscope. If now, an apparatus should be constructed in which the interference apparatus with the bars could be enclosed in a vacuum, with proper methods for measuring the temperature of the bars, it is probable that the method would be capable of giving results considerably more accurate than any heretofore used.

COLOR PHOTOGRAPHY BY LIPPMANN'S PROCESS. By Prof. CHAS. B. THWING, Evanston, Ill.

[ABSTRACT.]

IN a communication to the Académie des Sciences on the second of February last, Mons. G. Lippmann opened an entirely new line of experimentation on the problem of the photographic reproduction of the colors of nature. To Lippmann's account of his discovery is appended in Comptes Rendus a note by Mons. Edw. Becquerel to the effect that the process of Lippmann differs radically from the discovery made by himself in 1848, in that while Becquerel was able by photo-chemical means to produce a colored image of the spectrum which could not be exposed to light since the

action of the usual fixing agents reduced the deposit to a mere film of metallic silver, Lippmann, on the other hand, had by a physical process obtained an image which retains its colors after treatment with hyposulphite of soda, and is therefore as permanent as an ordinary negative. The peculiarities of Lippmann's method consist, first, in the use of a plate which is transparent and free from grains; second, in the exposure of the plate with its film side resting against a reflecting surface of mercury. The interference of the reflected with the incident ray of light divides the film into a number of layers at the maxima which will correspond in their distance apart with the wave length of the incident light, and will therefore be able to reproduce by reflection the color which produced the layers.

Lippmann says that the plates are positive for reflected and negative for transmitted light (négatif par transparence). By negative he means showing the complementary color. In that one of Lippmann's negatives which I have seen and all those obtained by myself, the plates are opaque to transmitted light, showing only differences of density like an ordinary negative. The reverse side of the plate, however, shows the complementary colors, somewhat fainter than the original colors which appear on the film side of the plate.

In my experiments I used both albumen and collodion films, securing transparency by reducing the proportions of the salts to about one-fourth the amount usually employed. The plates were exposed against mercury, not, however, to the spectrum, but to light transmitted by strips of variously colored glass, one object being to determine whether the ordinary colors of objects, consisting as they do of a mixture of rays of several different wave lengths, would be reproduced with the same fidelity as were the pure rays of the spectrum.

The results obtained, though by no means conclusive at all points, seem to indicate: First, that mixed colors may be reproduced with some fair degree of accuracy, modifications being introduced by a change of thickness of the film between exposure and final drying, and by a shortening of the distance between maxima caused by the ray's striking the reflector at an angle other than the normal. Second, that an exposure sufficiently long to give a clear image of the red is quite certain to obliterate the blue by over-exposure. Third, that an over-exposure may completely reverse the colors, causing the original colors to appear on the reverse, and the complementary on the film side of the plate.

[A number of negatives were exhibited illustrating the facts presented.]

ON THE BEHAVIOR OF SILVER BROMIDE EMULSIONS UNDER LONG EXPOSURE TO LIGHT. By Prof. CHAS. B. THWING, Evanston, Ill.

[ABSTRACT.]

A METHOD of studying the action of light upon the silver salts which should eliminate the action of developers ought to throw some new light both upon the nature and extent of that action.

In this investigation commercial plates from various makers were exposed by small sections to the direct action of sunlight, for periods varying from sixty minutes to one second, and afterwards cleared in hyposulphite of soda without development. The squares exposed for one minute or longer showed an image before clearing. After clearing and drying the image varied in color from a pale green to a dull yellowish green, according to the time of exposure, by reflected light, and a clear rose color by transmitted light.

If the plates were but slightly developed the longer exposures were reversed, becoming nearly transparent and of a faint lavender tint by transmitted light while the colors of the shorter exposures were heightened.

ARTIFICIAL RAIN. By H. A. HAZEN, P. O. Box 427, Washington, D. C.

[ABSTRACT.]

EVER since Espy's day the subject of producing rain at will has had very great interest and many studies of the problem have been presented. Of these studies one of the most exhaustive has been in collecting together all the battles of the war which were followed within twenty-four hours by rain. There were found 158 out of more than 2,000 which fulfilled this condition or a little over 7%. It does not seem at all surprising that out of so many cases there were 7% which had natural rain. An investigation has shown that in the battle of Bull Run, which had a terrific rain after it, the rain was first felt very abundantly at Charleston. To extend the period for the rain to fall to twenty-four hours is virtually to say that the concussions could not have produced the rain for in twenty-four hours the place in the atmosphere where the explosions were made would have moved about 500 miles to the eastward.

It has also been suggested that during the construction of the Central Pacific R.R. across the Sierra Nevada divide in California it was necessary to use vast quantities of gunpowder and this blasting was accompanied by great downpours, unheard of before or since in that region. Just the dates of this phenomenon are not given, but observations recently made have shown that in most of the months there are copious rains in this mountain region. It is not at all strange that the persons employed in the construction work and accustomed to the long periods of dry weather in the plains should be struck by the greatly increased rainfall in the mountains. The results of the present experiments in Texas will be looked for with great interest, but it should be distinctly understood that they cannot have any support from any studies or observations that have been thus far made.

ON THE NOMENCLATURE FOR PHYSICAL UNITS. By Prof. A. MACFARLANE, Austin, Texas.

[ABSTRACT.]

THE paper discusses the correctness of such an expression as kohms per cubic centimetre as the resistance is not proportional to the volume.

MAGNESIUM AS A SOURCE OF LIGHT. By FREDERIC J. ROGERS, Cornell University, Ithaca, N. Y.

NOTE ON MAGNETIC MEASUREMENTS AT OHIO STATE UNIVERSITY. By Prof. BENJ. F. THOMAS, Columbus, Ohio.

NOTES ON ROTATING CONTACT METHODS OF MEASUREMENT OF VARIABLE ELECTRIC MAGNITUDES. By Prof. BENJ. F. THOMAS, Columbus, Ohio.

OBSERVATIONS ON ATMOSPHERIC ELECTRICITY AT BLUE HILL OBSERVATORY. By ALEXANDER MCADIE, U. S. Weather Bureau, Washington, D. C.

[ABSTRACT.]

CONTINUOUS observations of atmospheric electricity have only been made at a few of the best equipped astronomical and meteorological observatories.

At the College de France, in Paris, the curves have been continued since 1881, at Perpignan since 1882, and at Greenwich, Lyons and the Parc St. Maur (near Paris), likewise for long periods. In the United States, continuous records were obtained by the Signal Service at Baltimore for a period of three years, and at Worcester and Amherst observations have been made for short periods. The chief cause of this paucity of observations is undoubtedly the difficulty of maintaining and manipulating the photographic register. The expense of a proper equipment is considerable, and the various difficulties that arise in installing the apparatus make it impossible to use the method elsewhere than in a well-equipped observatory. The ordinary form of Mascart self-register (and this is about the only apparatus free from grave theoretical errors) requires for a successful record, a dark room, stone piers, constant hygrometric and temperature conditions and the fixing of the record of photography. Observations

of the potential of the air can never therefore be general with such apparatus. It is also impossible where photography is used to know what the value of the potential is at any moment, a very important desideratum. The electrometer for successful general use, as for example, for the use at the various stations of the Weather Service, at experimental stations, etc., must first of all, be one giving a record that can be easily read at any hour of the day.

These considerations led to the construction of a new type of electrometer, known as the "Multiple quadrant electrometer," and a series of experiments to test its efficiency made at Blue Hill Observatory. The instrument is simply an enlarged Quadrant Electrometer, with the parts all so arranged as to be convenient of access, and instead of the four quadrants and small single aluminium needle, eighty quadrants and a needle with twenty blades are used; or it can be arranged to have forty quadrants and a ten-bladed needle. The great advantage of the curve given by the mechanical registering of the movements of the needle, is, as has been said, the possibility of seeing at each moment what variations in the potential of the air are occurring, and the possibility of directly comparing these changes with the changes in atmospheric pressure, temperature, humidity, wind direction, velocity, etc.

Thus far some excellent results have been obtained and while in sensitiveness, of course nothing can exceed or, indeed, even equal the bifilar suspension and ground glass scale (while photography can be equally sensitive, still it is worth while to remember that in practice, a very feeble light is generally used and the photographic record, while very delicate yet frequently has no record of the very rapid fluctuations) the sensitiveness of the new electrometer has been greater than was expected. The fluctuations due to distant thunder storms are easily discernible in the record.

Some very interesting experiments were made at Blue Hill, with two Mascart self-registering outfits, one at the summit, and one at the base, 126 metres below the summit and 1,178 metres northwest, using exactly similar instruments and methods to test whether or not a synchronism can be found in the daily periods and in the accidental fluctuations.

Curves exhibited at meeting:

1. Self-registering electrometer.
2. Curves of pressure, temperature, humidity, wind, velocity and direction.
3. Anemo-cinemograph curves.
4. Statoscope curves showing minute fluctuations in pressure.

[The expense of these experiments in part defrayed by a grant from the "Elizabeth Thompson Science Fund."]

ON THE LOGARITHMIC MEAN DISTANCE BETWEEN PAIRS OF POINTS IN ANY TWO LINES. By Prof. WILLIAM HOOVER, Ohio University, Athens, Ohio.

STATEMENT OF THE GENERAL LAW DETERMINING THE FUSING AND BOILING POINT OF ANY COMPOUND UNDER ANY PRESSURE AS SIMPLE FUNCTION OF THE CHEMICAL CONSTITUTION OF THE SAME. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[This paper will be printed in Zeits. für Phys. Chem. Leipzig.]

THE CALCULATION OF THE BOILING POINT OF A LIQUID UNDER ANY PRESSURE. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[This paper will be printed in Zeits. für Phys. Chem. Leipzig.]

DETERMINATION OF THE DISCONTINUITY OF THE FUSING POINTS OF PARAFFINS BY MEANS OF ANALYTICAL MECHANICS. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[This paper will be printed in Comptes Rendus, Paris.]

THE PERIODICITY OF THE AURORA. By M. A. VEEDER, M.D., Lyons, N. Y.

SOME FORMS OF CARBON AND ALKALINE STORAGE BATTERIES. By Prof. W. M. STINE, Ohio University, Athens, Ohio.

[ABSTRACT.]

THE ideal in designing accumulators is to obtain maximum output of energy with minimum weight. It is preferable to have this energy delivered at a reasonably high voltage per cell, with intensity, rather than simply quantity of chemical action; necessitating fewer cells for a given purpose. This ideal storage is doubtless that which would result from the decomposition of water on charging, with the subsequent reunion of the H and O on discharge. In the formation of water from its constituent gases more energy is liberated than in any other practical chemical reaction. Such a battery would develop a high voltage and store the most energy for a given current, while the mass of matter involved in the chemical reaction would be the least possible for an ampere of current. All this is clearly demonstrated in the so-called gas batteries of Grove and others. It is, however, acknowledged to be impossible to reduce this ideal battery to a practical working form, for the reason that gases act in such cases only in solution.

During the past year the writer has made a series of investigations on this type of battery, employing a modification of the carbon electrodes already used for the decomposition of water, and some of the results may have value. The high absorptive power of finely divided carbon for gases was utilized. Well burned animal charcoal was treated with HCl to dis-

solve out the mineral matter; it was then thoroughly washed and dried at a high temperature to expel the air absorbed while draining. This dried mass was moistened with a 40%, by weight, solution of sulphuric acid and packed in small Grove battery tumblers around the porous cups, which were also filled with the same mixture. Plain arc carbons were heated and inserted for the electrodes, and so connected as to make the carbon in the porous cup positive. A current of one ampere was generally employed in charging and the potential measured by the galvanometer-voltmeter method. A noticeable feature of these cells, was the rapidity with which they acted with a very small charge. The first charge was continued for five minutes and they behaved quietly and without gasing, except at the water line if made too moist. Such charges usually developed voltages ranging from .9 to 1.4 volts. They were then discharged through an electric bell of three ohms resistance, to determine relative efficiency. As an audible voltmeter, a bell possesses some merit. Its range was sufficiently wide, as it would ring with an E. M. F. of .1 volt, and one soon becomes so accustomed to it, that the voltage may be pretty accurately inferred from the intensity of the sound. The first five-minute charge given to a cell would usually ring the bell for nine minutes, and this increased by use to 15–25 minutes. Increasing the time of charge showed that the cell reached its limit of economical capacity in about ten minutes, when the voltage became 1.7 to 1.9. When pushed beyond this the cells would gas badly, though the voltage increased slowly and in some cases reached 2.79 volts.

The stability of the charge was, however, low. While standing charged for an hour, the voltage decreased considerably, and the decrease was more marked during the first hour following the charge, than subsequent ones. The output in watts was but slightly lower than when discharged at once. This greater immediate activity of the cells is doubtless due to a great extent to the amount of gas still remaining in solution; and the decrease upon standing must have been caused by the progressive absorption of the gases by the carbon, thus taking them out of solution and thereby increasing the internal resistance.

The cells were frequently allowed to remain charged for twelve hours when the voltage was invariably found to have dropped to .6 and .8 volts and in this condition they rang the bell for about ten minutes, showing a loss of at least 75% of the initial charge. Occasionally the charge had almost entirely disappeared by the end of this period. This was accounted for, in part at least, by the appearance of the O, or positive electrode, when withdrawn from the cell; it was invariably eaten and furrowed. In one case where the cell had been in use for some time, the electrode was found reduced to the thickness of a lead pencil. It resembled the worn zinc from a Leclanche cell, and the carbon appeared to have been consumed rather than simply disintegrated. The H, or negative electrode, in no case showed signs of corrosion, except, where by change of the polarity of the charge, it had been the positive carbon. Though this is not a new fact, yet it seems just at this time to be significant. This oxidation of the carbon finally led to an abandonment of these experiments.

Various forms of powdered carbon were tested, but the best results followed the use of cleansed animal charcoal, and the carbon dust employed for making arc light carbons. This latter form proved at least three times as efficient as animal charcoal.

The electrolyte was also varied. HCl gave inferior results compared with H_2SO_4 besides introducing the unpleasant odor of Cl. The hydrates of Na and K worked well, evidently by secondary decomposition, but the charge was rapidly dissipated.

A large cell on the same plan was prepared with carbon dust and saturated with a 20% solution of NH_4Cl. As was expected, this cell proved capable of receiving a considerable charge without gasing. The potential immediately after charging was 1.7 volts, which invariably fell to less than one volt on standing twelve hours. The cell was varied and many tests applied; the results were encouraging and seemed to indicate that it might be a good type to develop for some purposes, as it is light and inexpensive.

Not being aware at this time of what had already been accomplished in France with the so-called "alkaline" storage battery, my results gradually led me to experiment with this type. It had been my conviction for some time that a reversible primary battery would after all be the most efficient accumulator. My first experiments in this direction were made with an electrolyte of $ZnSo_4$ and $ZnCl_2$ in varying proportions, with electrodes of zinc and carbon plates. By means of the secondary reactions at the positive pole on charging, the various chlorine acids were formed and acted as a fairly good depolarizer on discharge. The potential was about 1.4 volts after standing for twelve hours, and neither the potential nor the charge seemed to weaken when allowed to remain for some days. Were this cell made light proof, and the proportions of the two salts carefully worked out, no doubt it would make an excellent and efficient accumulator, though the chlorine acids would decompose after a time.

Another cell of similar construction was filled with an electrolyte of $ZnCl_2$ and KBr saturated with Br. This free Br together with the Br liberated on charging formed an excellent depolarizer, and the charge seemed permanent. Though this type of battery has much to commend it, its odor is too offensive to admit of wide use; yet this objection might be obviated. It has since come to my notice that Mr. Charles S. Bradley of Yonkers, N. Y., patented a somewhat similar cell in 1885, based on the English iodide of zinc batteries. He claimed a voltage of 1.8 which was well maintained even when the battery was rapidly discharged.

Most accounts of the Edison-Lelande and the Chaperon-Lelande batteries make no mention of the fact that the battery is almost completely reversible, though not practically so in its present form, it may be. The inspection of the negative element in these cells suggested the attempt at reversal. A cell was constructed with a copper electrode surrounded by a mass of CuO and separated by a porous plate from the zinc. The electrolyte was KOH. The primary E. M. F. was slightly in excess of one volt. The cell was short-circuited until exhausted and then charged. The reversal was accompanied by some gasing at both poles but an examina-

tion showed that the oxide which had been reduced to spongy copper by the action of the cell was completely oxidized by the charge. The original voltage was restored as well.

From what has already been accomplished with the alkaline batteries, we may reasonably expect them to prove of great value in the future and the economical storage of electricity by chemical means may yet be attained by their development; for it now looks as if the lead battery has reached the ultimate improvement of which it is capable, and is withal so inefficient and full of faults that we can hope for no final solution of the storage problem by its use.

Since completing my experiments I have found that there are at least two French patents, which have been issued in this country, essentially embodying the reversal of the zinc-copper elements in an alkaline solution. They are those of Virloy, Commelin and Bailhache in 1886, and Desmazures in 1889. So far as is known the first practical application of these patents in this country was made on May 4, of the present year by Messrs. Waddell and Entz. These gentlemen propelled a street car in Philadelphia with great success, using 100 cells of this type, which weighed but 3000 pounds and developed an efficiency of something like 80%. These figures indicate a great advance both as to weight and efficiency over lead accumulators used for a like purpose.

Early in April I began a series of experiments to determine whether it was practicable to employ a depolarizer which should be soluble and at the same time reversible, but not affected by long standing as are the chlorine acids. After a number of preliminary tests the oxygen compounds of Br and Cl in alkaline solution were adopted. An inspection of the well-known reaction between Br and KOH,—

$$6KOH + 6Br = 5KBr + KBrO_3 + 3H_2O,$$

seems to indicate that at first the Br atoms unite directly with the six atoms of K, forming six molecules of KBr and setting six OH free. These hydroxyl groups would suffer an immediate decomposition into $3H_2O$ and three atoms of nascent O, which seizing upon the nearest KBr molecule would form the molecule of $KBrO_3$ indicated by the equation. That this may be the correct explanation of this reaction is confirmed by the oxidation of a solution of KBr by even the passage of O gas through it, as well as by the action of $KMnO_4$ and other oxidizing agents.

These experiments resulted in the development of two types of batteries which yielded excellent results both as regards weight and efficiency. In both light strips of zinc were employed as negative, and carbon rods or plates, as positive poles. When designed to be used immediately as a secondary battery the one was filled with an electrolyte of K_2ZnO_2, KOH, and KBr with a little $KBrO_3$; the other with Na_2ZnO_2, NaOH, NaCl and $NaClO_3$. The latter solution owing to the high solubility of the salts of the chlorine acids, possesses greater storing capacity than the other; though that seemed to produce the highest voltage, which in some cases reached 2.25 volts. The $KBrO_3$ solution is to be preferred too, on

account of the greater sensitiveness of $KBrO_3$ and KBr in the action of the cell, and the $KBrO_3$ has proven sufficiently soluble in this menstruum to make an efficient depolarizer. Judging from the behavior of a large cell of three pairs of elements, it seems reasonable to state that an E. H. P. hour can be stored in from 25 to 30 pounds of battery. These cells were in no case injured by very high rates of charge and discharge.

In the Scientific American Supplement for Aug. 8, 1891, is given an account of the successful manufacture in France of $KClO_3$ by the electrolysis of KCl. This process has not only proven cheaper, but it is quicker and simpler than the usual chemical methods. It is certainly a striking confirmation of what has just been said.

Several experiments were made to test the depolarizing quality of $KBrO_3$. 50 cc. of a 1-10 solution of KOH was placed in a beaker and carbon electrodes inserted, and the cell thus made connected to the bell and the galvanometer in shunt. The E. M. F. at first was .8 volts, which fell in an hour to .36, owing largely to polarization. To a cell similarly made and connected, some Br water was added. Owing to the weakening of the electrolyte through the formation of $KBrO_3$, and KBr, the galvanometer indicated but .63 volts, which at the end of three hours continuous ringing of the bell had fallen to .57 volts. After six hours it registered .36 volts and at the end of $15\frac{1}{2}$ hours of continuous activity showed .26 volts. When account is taken of the size of the cell,— it was in a two-ounce beaker; and the work performed,—that of continuously ringing a bell for more than fifteen hours whose figure of merit was .1 ampere: the results are significant.

So far as the stability of the charge in these batteries is concerned, experience has shown that if proper care be taken in their construction, the loss through local action is very small when remaining charged for weeks. I have recently tested one cell which had stood exposed for at least six weeks, and could detect no appreciable deterioration.

OBSERVATIONS WITH A NEW PHOTOMETER. By NELSON H. GENUNG and FREDERICK J. ROGERS, Ithaca, N. Y.

WHAT SHOULD BE OUR FUNDAMENTAL UNITS? By Prof. BROWN AYRES, Tulane University, New Orleans, La.

THE NATURE OF "COUNTER-ELECTROMOTIVE FORCE." By Prof. BROWN AYRES, Tulane University, New Orleans, La.

NOTE ON THE MEASUREMENT OF RESISTANCES BY ALTERNATING CURRENTS. By Prof. BROWN AYRES, Tulane University, New Orleans, La.

THE TANGENT GALVANOMETER AS A VOLTMETER. By Prof. W. M. STINE, Ohio University, Athens, Ohio.
[This paper will be printed in the Electrical Review.]

DO TORNADOES WHIRL? By H. A. HAZEN, P. O. Box 427, Washington, D. C.

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ADDRESS

BY

PROFESSOR R. C. KEDZIE,

VICE PRESIDENT, SECTION C.

ALCHEMY.

When I announce alchemy as the subject of my address, a word of apology is due for selecting a subject so outgrown and alien to the spirit of the age. It is not to revive the wild theories and chimerical hopes of the past that alchemy is brought before you at this hour. Yet it is always interesting to trace the evolution of a science, and to note its unfolding and progressive development; like the breaking of the morning. The dawn reveals wild shapes and distorted forms; the shadows of sunrise stretch out limitless; but with the onward sweep toward full day, portentous forms, and endless shadows settle down to the safe and quiet realities of every-day life. So the wild dreams of that dawn of science have subsided into the assured facts of chemical science. Alchemy is often called the forerunner of chemistry, and out of its broken columns there has been built up the enduring temple of chemical science. No science has a more enduring basis of known facts than chemistry, and none can more calmly examine the basic principles upon which it is built without fear that the foundation stones will turn to dust upon the touch of investigation.

But no science comes to us like Minerva leaping from the brain of Jupiter—"adult and full armed"—possibly because Jupiters are so rare, and the bold surgery of Vulcan so seldom invoked. The passage from alchemy to chemistry is full of suggestions and has often been considered, but usually by contrast rather than by comparison. One filled the world with vast hopes but unsatisfied long-

ings; the other has crowned the race with benefactions. Yet the results of the labors and discoveries of the alchemists have been of great value to the world even though the direct objects they sought forever eluded their grasp and left disappointment and despair to their votaries. More than a hundred years ago Harris tersely described alchemy, "Ars sine arte, cujus principium est mentiri, medium laborare, et finis mendicare,"—the art without art, whose beginning is to lie, the middle to toil, and the end to beg.

We are prone to look back upon this nebulous science with disdain as the product of an age that had full confidence in magic and sorcery, that could accept without hesitation the elusive nature of matter, yet find no difficulty in the belief in the resistless power of occult forces. But let us be candid even in our review of ancient error. Let us see what were the hopes and aspirations of these hermits of science, and see how modern thought stands related to ancient dreams—whether we find in scientific thought, the same as in matter, a tendency to move in recurring cycles.

The objective points of the alchemists were:

1. *The Elixir of Life*—panacea—all-cure—a substance which would confer quasi-immortality upon any one who should swallow it, curing all sickness, assuaging all pain, and transforming hoary age into blooming youth. It was even more eagerly sought than the transmutation of metals. Life is the highest gift and, without it, all other blessings turn to ashes. "All that a man hath will he give for his life." But the crowning of life is health. It is not wonderful therefore that men in all ages have sought under various names the elixir of life.

The alchemists regarded gold as the king of metals, and its symbol was the sun — the giver of light and life. When the Spaniards discovered such astonishing quantities of gold in America, they were confident that some form of the elixir of life was hidden away somewhere in the mysterious continent, and many parties were formed to explore its solitudes in quest of this great gift. For this, Ponce de Leon and his faithful band pierced the swamps of Florida, seeking "the fountain of youth," where their leader was wounded to his death. But these were only the vanguard of a countless host that is still marching on.

The alchemists regarded gold as the most perfect form of matter; unalterable by fire, incorrodible by air, water or any simple acid. Its very insolubility was proof of its excellence. This per-

fection of matter must be able to impart its properties to perishable forms of matter, and "potable gold" was supposed to be the elixir of life.

Roger Bacon was convinced that auric chloride was this elixir, and he informed Pope Nicholas IV of the case of an old farmer in Sicily who plowed up a golden vial containing a yellow liquid, which he swallowed supposing it to be dew, whereupon he was transformed into a vigorous youth.

Others sought the elixir as an essence derived from the distillation of a great number of substances, while the Hindoos supposed the Amreeta was obtained by churning the sea with a mountain.

We smile with superior air at such fantastic imaginings, yet not long ago the world went wild over Brown-Sequard's elixir of life—extract of mutton!

2. *The Alcahest.* The alchemists searched for some substance that would dissolve all other substances—alcahest, or universal solvent. Crookes forcibly suggests that this is found in fluorine.

3. *The Philosopher's Stone*, having the same purifying and ennobling office for mineral matter that the elixir of life would have on animal forms. By means of this substance they could effect the transmutation of base metals into perfect metals, "curing them of their sickness and perfecting their nature," thus changing copper to gold and lead to silver — performing "the great work" by projection of the philosopher's stone on base metals in presence of great heat.

Such were the dreams, the hopes, and the endeavors of the alchemists—life prolonged at pleasure—health perennial—wealth beyond measure. It was a great hope, and it was slow to die. The things sought are indissolubly interlinked with the desires if not the expectations of humanity. Nothing debasing entered into this scheme, but rather the aim was to ennoble man and matter, and out of base material to bring forth the flower and fruit of perfection. To a degree man would become a creator and a semblage of omnipotence would be placed in the hands of mortals, not merely by linking himself with the powers of nature and clothing himself with their immeasurable might, but by subduing these forces and compelling them to surrender their secrets and do his bidding. By torture nature could be taught to obey, and become the slave of her mortal child, and the *crucible* became the instrument and symbol of this power.

If the hope of such mastery and of victory laden with so rich spoils was held out to the children of the 19th century, would they exhibit a superiority to the visionaries of the 13th century? It was the gambling spirit of the olden time, and man sought to use loaded dice in his game with nature.

Consider, also, how slowly the dreams of alchemy have given place to the wide-awake facts of chemistry. The great Napoleon, during his campaign in Egypt, sought initiation into the dark mysteries of Egyptian secret art. Napoleon III, before he ascended the French throne, had in his service those who attempted the transmutation of baser metals into gold. Dumas thought gold might be an allotropic form of copper, and silver allotropic lead; and Sir Humphrey Davy told the elder D'Israeli that he did not consider the undiscovered art of transmutation an impossible thing.

About three years ago, in a neighboring city, an alchemist exhibited to a leading business man his ability to multiply gold by heating a gold coin with the philosopher's stone in a crucible, and removing from the crucible a mass of gold weighing three times as much as the original coin. Other business men witnessed a similar operation, and became so fully convinced of his power to increase the amount of gold three-fold that they formed a company to multiply gold by digestion with the philosopher's stone. Gold coin to the amount of $90,000 was placed in an iron digestion vat with a quantity of the philosopher's stone. The vat was placed over a fire in a furnace built for the purpose, an iron lid placed over the vat, and securely locked, the furnace room locked and all the keys placed in the hands of the gold-multiplying company (unlimited), with strict orders that the vat must not be opened under three weeks. The alchemist having been called away on business to another city and not returning at the appointed time, the gold company became suspicious and opened the vat, only to find the gold gone, and some stones and scrap iron in its place. It was the *gold* that had been transmuted.

A few months ago the same sharper was arrested in London for attempting a similar fraud, and when arraigned in the criminal court the police magistrate said "it was just possible that Pinter might have discovered some method of increasing the weight of gold." Among the victims of Pinter's Philosopher's Stone, a member of the house of Rothschild and of Baring Brothers are

mentioned. Who shall say that faith in "the great work" has left the earth!

A few days ago at the Old Bailey he was sent to prison for swindling.

The ancients arguing from analogy supposed that metals grew like vegetables, only the growth was subterranean; and there was a vain search for the seeds of metals. Foiled in this quest they thought that metals passed upward by successive development by a sort of evolution, the base metals being progressively changed to those of a higher order till perfect metal such as gold was formed. A third conception was that metals are composite, made up of some basic matter or earth, and phlogiston. The notion of the composite character of a metal was perhaps the most damaging error of the alchemists. With them a metal was not a simple body, but the union of an earth with an inflammable matter; that the metalline character resided in the phlogiston rather than in the earth, that the greater the quantity of phlogiston combined with the earth the more perfect was the metalline character brought out, and if we could combine enough phlogiston with any earthy body we could form metals even of the most perfect character. Even Macquer in his dictionary of chemistry (1776) is in doubt whether the kind of earth determines the character of the metal to be formed by adding phlogiston, and whether the real difficulty did not lie in securing sufficient phlogistication of intractable earths.

The perfect metal, gold, was considered to have an oily or unctuous quality, and the fact that oils contained a large amount of phlogiston was considered significant. To secure the oily quality of a perfect metal, oils were favorite sources of phlogiston; and it was claimed that if intractable earths were fused with oil in an accurately closed vessel, perfect metals could be secured. Nor was this mere theory. Beccher proposed to the State's General to procure gold from any kind of sand and claimed to demonstrate the same by his famous experiment of *Minera arenaria perpetua*, building his house on the sand very literally. So Beccher and Geoffroy proposed to obtain iron from all clays by heating them with linseed oil in close vessels.

The alchemists reasoned that if phlogiston were accepted as the metalliferous principle, the combination of which with any earth would convert it into a metal, and the escape of which would reduce any metal to an earth, then the transmutation of one metal

into another metal would seem no more difficult than the transformation of earths into metals.

The phlogistic theory of Beecher and Stahl was considered a great advance in its day because it enabled the chemist to classify all the then known facts of chemistry. But it soon became a bar to scientific progress, and with its overthrow a new era dawned in science.

The change of a metal into another metal was not a mere theory with the alchemists; they saw repeated proofs of this transmutation. By the purifying influence of fire they made purest silver out of unquestionable lead, and the silver medals attesting this fact which Dr. Bolton lately found in Austria were the *ecce signum* of the alchemists. The Chinese still hold that lead kept in fusion for 200 years becomes silver; and silver similarly treated changes to gold. What the alchemists required was some means to quickly transmute the whole of the lead into silver and prevent the large loss of lead when fire alone was used. The truth wrongly interpreted only led them wider astray.

The conception also of the instability of the properties of matter—that, for example, color, lustre, weight, malleability, fixedness in the fire, etc., are properties that may be imparted to a body destitute of them irrespective of the nature of such body, just as a man may change his clothes without changing his person, was most misleading for the alchemists. "If the property is separate from the substance, like our apparel, let us clothe copper with the properties of gold and thus make it gold."

The theory of the instability of matter was the quicksands that swallowed up scientific progress for the alchemists.

The indestructibility of matter, and the possibility of recovering a given substance notwithstanding all its disguises by combination with other bodies—the persistence of matter and the immanence of its properties,—were grand discoveries in material science. They marked the transition from alchemy to chemistry.

The recognition of the indestructibility of force was the second great step, the crowning discovery of modern physics. In the words of Faraday, "it is the highest law in physical science which our faculties permit us to perceive."

Shall we take a third step and proclaim the permanence of force but the destructibility of matter—that the atom may have a life, grow old, and die, or pass back into primitive no-thing-less, or be-

come the ether of which we talk so much and know so little? Shall we assume that radiant force may be changed into matter and fall under the law of gravitation?

ATOMIC THEORY.

No single thought has contributed so much to give form and permanence to chemical science as the atom of Dalton. An atomic theory was indeed held by the Greeks in regard to the constitution of matter, but it related chiefly to the question of the continuity or discontinuity of matter in mass, and considered the question of the limited or unlimited divisibility of matter. But the chemical atom, with its application in explaining the law of definite and of multiple proportions by weight in chemical combinations, was the gift of the Quaker schoolmaster of Birmingham. It has furnished not merely a basis for nomenclature and notation, but has given form and substance to chemical science. Like a sentinel rock it lifts its immovable form amid the shifting waves and tides of chemical theories. Shall the chemical atom finally be relegated to the limbo of exploded theories and creeds outgrown? The question is perhaps nearer our doors than we had suspected.

GOLD MAKING (?)

The question has been seriously raised by an eminent American chemist whether gold can be manufactured. On the affirmative side of this question he points to the fact that didymium has been split into two metals and by recombining these two new metals the old didymium was again formed. He also points out the complex nature of yttrium as shown by Crookes by means of the spectroscope, and then proceeds to say: "These facts and many others that could be given, make it probable that the so-called chemical elements are not really elements, but compounds, which in time we shall be able to separate into their constituents, and conversely to reproduce by combining other substances."

"Among the heavy elements—and hence those that would be expected to yield to the searching attacks of the chemist—is gold. It is not improbable that in time it will become possible to make gold in large quantities—an event which would throw it out of use as a standard of value, so far as it derives its own value from its rarity[1]."—

At first sight this might appear to be a chemical canard, but the

[1]North American Review, Sept., 1890, p. 377.

writer proceeds to point out the social and financial results of cheapening of gold.

The statement that didymium is a compound metal is of great interest to the chemist. But the fact that the reunion of these metals will form the old metal or alloy is not so surprising, but is what any chemist would expect. But how do such facts show the probability or possibility of making any given metal out of heterogeneous materials? If the combination of cerium and samarium would form didymium, then a plausible case would be made out. But if praseodymium and neodymium are required to make didymion, how are we nearer the manufacture of this last metal by such discovery? We must still have the two new metals to make the old metal. Suppose that gold can be split into two or ten new metals, the reunion of which will form gold, does this bring us one whit nearer the new age of gold? If it takes gold to make gold, what part or lot have the baser metals in such transformations?

The trend of recent discoveries is to increase the number of simple or elementary substances. The simple nature of any substance has only been held provisionally — regarded as elementary until its compound nature is shown by exhibiting the separate elements of which it is composed. The more recondite the appliances for investigation, the more complete the differentiation of matter, the greater will be the number of elementary substances, and yet we shall be as far as ever from the ability to change one metal to another.

The question of the primary and essential nature of matter belongs to metaphysics rather than physics. Yet the nature of matter as well as its properties is a vital question in chemistry. The chemist has made certain basic propositions the foundation of his science. The essential immutability of matter is a corner stone. Weight and measure have no place in a science that deals with matter essentially variable in its nature; but it is weight and measure that have made chemistry the most exact of all natural sciences.

PANTOGEN.

The idea of an original simple matter as the basis from which all things have been formed is not wholly modern. Duns Scotus advanced the idea that the basis of universal existence was a *Materia primo-prima*, by the differentiation of which the individual is formed. About twenty-five years ago a modified form of this theory

was brought forward by Professor Hinrichs of Iowa who advanced his theory of *Pantogen* or *Urstoff* to explain the constitution of matter. There was only one simple or elementary matter—*Urstoff*—and as all forms of matter are produced from this primary matter, he called it *pantogen* and the products formed by the reduplication of this simple matter he called *panatoms*. His argument was based upon a parallelism between astronomy and chemistry. "The basis of this celestial mechanics (astronomy) is only an hypothesis that of universal gravitation—which essentially consists in the affirmation that the heavenly bodies only differ in regard to the amount or quantity of matter."

"Let us have the boldness to pronounce a similar hypothesis in regard to chemical atoms. Let us suppose that the atoms of the different elements only differ in regard to quantity — that is, in regard to the number and relative position of the atoms of some one primary matter, just as the planets only differ according to the number of kilograms of ponderable matter they contain and its distribution around their axes. Since everything would be composed of this one primary matter we call it *pantogen*, and its atoms *panatoms*."

This programme of atomechanics was caustically reviewed in the Chemical News, Dec., 1867, which pointed out the fact that Professor H., like all discoverers of his class, continually falls back on analogy. "This too free use of analogy has been the bane of science from the time of Plato, and it would appear that the race of speculators who mistake fanciful analogies for fundamental scientific laws is by no means yet extinct."

The reviewer closes by urging Professor Hinrichs as the crowning feat of his discovery, and that which would compel the adhesion of scientific men to the new theory, "*to isolate pantogen*."

Has the whirligig of time brought the keen editor and sharp reviewer around to face urstoff and panatoms?

THE GENESIS OF ATOMS.

How was the atom formed? Was it coeval with matter? Or did matter antedate the atom? Was there *prima materia—pantogen*, *protyle*, *urstoff*—out of which the atom was formed by reduplication of urstoff upon itself? Do heredity, selection, environment and discriminative destruction explain atomic formation, and the discrimination of atom from atom in the domain of chemistry? "A

theory of evolution of this kind," says Clerk Maxwell, "cannot be applied to the case of molecules, for the individual molecules neither are born nor die, they have neither parents nor offspring, and so far from being modified by their environment, we find that two molecules of the same kind, say of hydrogen, have the same properties, though one has been compounded with carbon and buried in the earth as coal for untold ages, while the other has been occluded in the iron of a meteorite, and after unknown wanderings in the heavens has at last fallen into the hands of some terrestrial chemist."

When we attempt to apply the process of discriminative destruction the trouble increases, for "we should have to account for the disappearance of all the molecules which did not fall under one of the very limited number of kinds known to us; and to get rid of a number of indestructible bodies exceeding by far the number of the molecules of all the recognized kinds, would be one of the severest labors ever proposed to a cosmogonist." The "missing links" would form the principal chain.

But Mr. Crookes finds, by means of an interpretative illustration of the periodic law, an explanation of the formation of matter out of *protyle* with segregation into atoms of definite valence and proximate molecular weight.

The discovery of the periodic law of chemical elements was a long stride in scientific progress. It bids fair to be as masterful in chemistry as universal gravitation in astronomy, and a certain analogy may be traced between them. The planets have certain orbits around the sun and velocities of revolution proportional to their mass. Did position fix their mass, or mass determine their position? By the periodic law, the atom having a certain mass or weight falls into a certain position. Is the mass of an atom determined by its position, and not rather the position determined by its mass? Does the periodic law require us to consider the properties of matter as mathematical functions of numbers, and thus reproduce the Pythagorean philosophy of number and harmony, that "all things are number, and that number is the essence of everything—the elements of numbers are the elements of existence."

Or have position and force acquired the properties of matter?

SPECTROSCOPE.

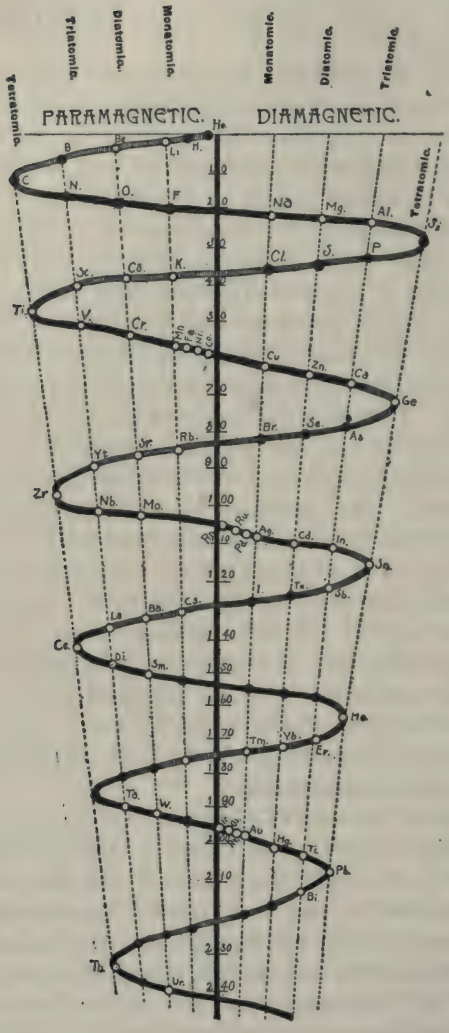
If there was ever a flank movement on nature by which she has been compelled to surrender a part of her secrets it was the dis-

covery of the spectroscope, "which enables us to peer into the very heart of nature" (Crookes). It is the open sesame of physics and chemistry. If biology could lay its hands on a similar instrument to unlock the secrets of life, what fields of discovery would unfold before the explorer!

By means of the spectroscope, we may question the very elements and submit them to cross-examination in the court of science. Surprising results have thus been reached, but the trend seems to be all in one direction—to show the complex nature of what was supposed to be simple matter — that didymium, *e. g.*, was not a simple body but contained at least two metals—was twin in more senses than one. It was much the same as Davy's showing that potash was not a simple body, anomalous among chemical substances, but contained a metal and thus fell into line in chemical combinations. But does the discovery of even a nest full of metals where only yttrium was supposed to be, require the assumption of meta-metals—stuff which has not yet grown to the full measure of a metal; shall we suppose that each *ultissimum elementum* has only one line in the spectrum and that the spectroscope will yet reveal swarms of meta-metals in the chemical system just as the telescope calls out the countless stars from the milky way?

On the other hand does the splitting up of the rare metals justify the assumption that the metals most fixed in character, and which show no tendency to split into meta-metalism such as gold and platinum, are compound in constitution and may be compounded out of baser materials? Crookes' suggestion that what comes to us as copper has been shunted upon the wrong track in its passage from aboriginal elemental matter to make gold, holds out small hope to metallic transmutation.

In the use of the scientific imagination few men can compare with the editor of the Chemical News. Let us briefly follow Mr. Crookes in his scheme of the genesis of the elements out of ante-elemental material — protyle — urstoff — immaterial matter out of which matter may be formed by a process of condensation through the cooling down of the original fire mist until it acquires elemental properties. By a process of polymerization of protyle, or reduplication of dissociated matter, with fall of temperature and acquisition of different amounts of electricity, he supposes the elements are evolved as known to us. Assuming the periodic law of Newlands and Mendeleeff, and modifying its graphic representation by


Tetratomic.
Triatomic.
Diatomic.
Monatomic.
Monatomic.
Diatomic.
Triatomic.
PARAMAGNETIC.
DIAMAGNETIC.
He.
H.
Li.
B.
Be.
C.
N.
O.
F.
Na
Mg.
Al.
Si.
P.
S.
Cl.
K.
Ca.
Sc.
Ti.
V.
Cr.
Mn.
Fe.
Co.
Ni.
Cu.
Zn.
Ga
Ge
As.
Se.
Br.
Rb.
Sr.
Yt.
Zr
Nb.
Mo.
Ru.
Rh.
Pd.
Ag.
Cd.
In.
Sn.
Sb.
Te.
I.
Cs.
Ba.
La
Ce.
Di.
Sm.
Ta.
W.
Os.
Ir.
Pt.
Au
Hg.
Tl.
Pb.
Bi.
Th.
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1·0
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1·80
1·90
2·00
2·10
2·20
2·30
2·40

Professor Reynolds, he pictures to the mind how the elements may have been formed out of matter in the ultra-gaseous condition by cooling down below the temperature of elemental dissociation, when out of the swarming myriads of ultra-elemental matter the elements may group into knots at nodal points. Around a central line—electrically, magnetically and chemically neutral—the length of the line marking the fall of cosmic temperature, the mighty gravitative force swings like a pendulum, but with lemniscate motion through space of three dimensions, and thus the atoms are formed and the elements appear, from hydrogen to uranium.

I quote: "In the undulating curve may be seen the action of two forces: one acting in the direction of the vertical line, and the other pulsating backwards and forwards like a pendulum. Assume the vertical line to represent temperature slowly sinking through an unknown number of degrees, from the dissociation point of the first formed element down to the dissociation point of those last shown on the scale. But what form of energy is represented by the oscillating line? Swinging to and fro like a mighty pendulum to points equidistant from a neutral centre; the divergence from neutrality conferring atomicity of one, two, three and four degrees as the distance from the centre is one, two, three or four divisions; and the approach to, or retreat from, the neutral line deciding the electro-negative or the electro-positive character of the element—all on the retreating half of the swing being positive and all on the approaching half negative,—this oscillating force must be intimately connected with the imponderable matter, essence or source of energy we call electricity.

"Let us examine this a little more closely. Let us start at the moment when the first element came into existence. Before this time matter, as we know it, was not. It is equally impossible to conceive of matter without energy, as of energy without matter. From one point of view the two are convertible terms. Before the birth of atoms all those forms of energy which become evident when matter acts upon matter, could not have existed—they were locked up in the protyle as latent potentialities only. Coincident with the creation of atoms all those attributes and properties which form the means of discriminating one chemical element from another start into existence fully endowed with energy.

"The pendulum begins its swing from the electro-positive side; lithium next to hydrogen in simplicity of atomic weight is now

formed, then glucinum, boron and carbon. Definite quantities of electricity are bestowed on each element at the moment of its birth, and on these quantities its atomicity depends and the types of monatomic, diatomic, triatomic and tetratomic elements are fixed. The electro-negative part of the swing now commences. Nitrogen appears below boron a triatomic element and therefore nitrogen is triatomic, but following carbon a tetratomic body, it occupies the fifth position counting from the place of origin, making its atom capable of acting as triatomic and pentatomic. With oxygen and fluorine the same law holds, and one-half oscillation of the pendulum is completed. Again passing the neutral line the electro-positive elements sodium (monatomic), magnesium (diatomic), aluminum (triatomic), and silicon (tetratomic) are successively formed, and the first complete oscillation of the pendulum is finished by the birth of the electro-negative elements phosphorus, sulphur and chlorine."

With successive swings of the generative electric pendulum, but in different planes because of progressive fall of cosmic temperature, the succeeding elements are formed on the same plan when their elemental dissociation temperatures are passed. The aggregating of protyle gives increased atomic weight from H = 1 to Ur = 239. The outward swing gives the electro-positive elements; the inward swing forms the electro-negative; the degree of electrization determines the atomicity and the position on the left or right of the neutral line determines the magnetic quality—para- or diamagnetic.

Such a scheme of the genesis of the elements fires the imagination with the loftiest conceptions; so many things fall into line and order. The very hiding place of missing elements seems to be pointed out, and newly discovered metals fall into their foreordained places prepared for them before the foundation of the worlds.

It would seem presumptuous to question a theory so beautiful and satisfying; but its foundations are assumptions of a sweeping character. If we concede the existence of matter without the properties of matter, we have yet to learn how it can acquire the properties of matter.

If we concede that it is ultra-material because of heat how can it part with heat before it acquires radiant power—a property of matter? We might also be tempted to inquire, what has become of the heat which once held the universe in the ultra-gaseous con-

dition? But leaving out of consideration ultra-material matter, let us glance at the probabilities in regard to matter already formed by polymerization of *protyle* or *protylic* aggregation, to see if we find that progression of properties to be expected by corresponding aggregations of formative one-matter. Mr. Crookes himself, frankly admits this difficulty, in his address to the Chemical Society: "As we review the series of elements . . . . we cannot fail to be struck with a consideration which at first sight appears absolutely fatal to the notion of the production of the elements from a series of "knots" as just described. If the elements which we call aluminum has been formed from ultimate atoms, having rates of vibration of the rate 27, or a little more or less, so as to give a mean of 27, and if the atoms between aluminum and the next element in the series, have in this manner been sorted out to the one hand or the other, leaving a void between, we should expect that their properties would not differ very widely from each other, or at least, they would present considerable analogies. Now, to a certain extent, this is actually the case. Upon aluminum follows silicon. We may, perhaps, conceive these two elements as springing from the differentiation of a nearly homogeneous swarm of ultimate atoms. But, if we pursue the curve onward, what elements follow? Phosphorus, sulphur, chlorine, bodies heterologous with each other, and heterologous with silicon. We can scarcely imagine original atoms, so to speak, in doubt which of two aggregations they should join, the one being silicon and the other phosphorus. Nor can we conceive of anything being split off from sulphur which should make even the slightest approach to chlorine.[1]"

Similar difficulties are found in other parts of the elemental curve. Nitrogen, oxygen and fluorine follow carbon with small differences of rate of vibration or atomic mass, but with no hint of associated properties. From fluorine we pass to the strongly contrasted sodium, and on the return swing from chlorine to potassium. Stronger contrasts of properties could hardly be found, yet these substances are next of kin in atomic weight. If the reply is that they stand on opposite sides of the line of neutrality, how happen the analogous metals sodium and potassium on opposite sides of the same line? In the three families of triplets—iron, nickel and cobalt—rhodium, ruthenium and palladium—iridium, osmium and platinum, how do these all fall into the monatomic

[1] Chemical News, June, 1888, pp. 226–7.

position? The explanation that each metal of the triplet is almost the other may satisfy some, but no explanation why a diatomic metal should fill a monatomic position has yet been offered.

Nor is the theory of the successive formation of elementary atoms with their progressive increase of atomic weight by reason of the fall of temperature below the point of elemental dissociation entirely satisfactory. It is claimed that hydrogen and then lithium first appear in the elemental condensation because with them the diminution of temperature at which elemental dissociation ceases is reached first of all, the heat being still too great for other bodies to exist even as elements. The heavy metals such as platinum and gold with large atomic weight are formed later in time because a vast reduction of cosmic heat was necessary before dissociation would cease and elemental consociation become possible. Do platinum and gold give indications of a tendency to dissociation more marked than that of lithium when questioned by heat, electricity and chemical action, or even when cross-examined by the spectroscope? Does not gold exhibit an integrity worthy of a noble nature? Does it hold out to alchemy the most distant hint of a multiple nature by means of which she may hope to divide and conquer?

The hypothesis of the evolution of the chemical atoms by aggregation or polymerization of one matter substance challenges scientific thought. Based upon broad assumptions and sustained entirely by analogy, it will hardly disturb the relative coinage value of the metals by holding out hopes of alchemic transmutation. The advice of Mr. Crookes to treat it simply as a provisional hypothesis is conservative and wise.

Ninth Annual Report of the Committee on Indexing Chemical Literature.

The Committee on Indexing Chemical Literature respectfully presents to the Chemical Section its ninth annual report.

Since our last meeting the following bibliographies have been printed:

1. A Bibliography of Geometrical Isomerism. Accompanying an Address on this subject to the Chemical Section of the American Association for the Advancement of Science at Indianapolis, August, 1890, by Prof. Robert B. Warder, Vice President. Proceedings A. A. A. S., Vol. xxxix. Salem, 1890. 8vo.

2. A Bibliography of the Chemical influence of Light; by Alfred Tuckerman. Smithsonian Miscellaneous Collections No. 785, Washington, D. C., 1891. pp. 22. 8vo.

3. A Bibliography of Analytical Chemistry for the year 1890, by H. Carrington Bolton. J. Anal. Appl. Chem. v, No. 3. March, 1891.

We chronicle the publication of the following important bibliography.

A Guide to the Literature of Sugar. A book of reference for chemists, botanists, librarians, manufacturers and planters, with comprehensive subject-index. By H. Ling Roth, London, Kegan Paul, Trench, Trübner & Co. 1890. 8vo. pp. xvi-159.

This work contains more than 1,200 titles of books, pamphlets and papers relating to sugar. Many of the titles are supplemented with brief abstracts. The alphabetical author-catalogue is followed by a chronological table, and an analytical subject-index. The compilation extends to the beginning of the year 1885, and the author promises a supplement and possibly an annual guide.

This ambitious work is useful but very incomplete; it does not include glucose. The author gives a list of fifteen periodicals devoted to sugar, and omits exactly fifteen more recorded in Bolton's *Catalogue of Scientific and Technical Periodicals* (1665–1882) (Washington, 1885). Angelo Sala's *Saccharologia* (Rostock, 1637), is not named, though mentioned in Roscoe and Schorlemmer and

elsewhere. Notwithstanding some blemishes this work is indispensable to chemists desirous of becoming familiar with the literature of sugar. It is to be hoped that a second edition brought down to date may be issued by the author.

4. A Bibliography of Ptomaines accompanies Prof. Victor C. Vaughan's work. Ptomaines and Leucomaines, Philadelphia, 1888 (pages 296-314). 8vo.

Chemists will hail with pleasure the announcement that a new Dictionary of Solubilities is in progress by a competent hand. Prof. Arthur M. Comey of Tufts College, College Hill, Mass., writes that the work he has undertaken will be as complete as possible. "The very old matter which forms so large a part of Storer's Dictionary will be referred to, and in important cases fully given. Abbreviations will be freely used and formulæ will be given instead of the chemical names of substances, in the body of the book. This is found to be absolutely necessary in order to bring the work into a convenient size for use. . . . . The arrangement will be strictly alphabetical. References to original papers will be given in all cases . . . "

Professor Comey estimates his work will contain over 70,000 entries and will make a volume of 1,500 to 1,700 pages.

The following letter from Mr. Howard L. Prince, Librarian of the U. S. Patent Office, explains itself.

UNITED STATES PATENT OFFICE.

Washington, D. C., February 11, 1891.

DR. H. CARRINGTON BOLTON, University Club, New York, N.-Y.

DEAR SIR:—In response to your request I take pleasure in giving you the following information regarding the past accomplishments and plans for the future of the Scientific Library in the matter of technological indexing.

The work of indexing periodicals has been carried on in the Library for some years in a somewhat desultory fashion, taking up one journal after another, the object being, apparently, more to supply clerks with work than the pursuance of any well-defined plan. However, one important work has been substantially completed, viz.: a general index to the whole set of the Scientific American and Supplement from 1846 to date.

It is unnecessary for me to point out to you the importance of this work embracing a collection which has held the leading place in the line of general information on invention and progress, the labor of compiling which has been so formidable that no movement in that direction has been attempted by the publishers except in regard to the supplement only, and that very imperfectly. This index embraces now one hundred and eighty-

four thousand cards, not punched, and at present stored in shallow drawers and fastened by rubber bands, and of course, they are at present unavailable for use. There is little prospect of printing this index and I have been endeavoring for some time to throw the index open to the public by punching the cards and fastening them with guard rods, but as yet have made no perceptible impression upon the authorities although the expense of preparation would be only about $70.00.

There has also been completed an index to the English journal "Engineering," comprising eighty-four thousand cards, from the beginning to date.

An index to Dingler's Polytechnisches Journal was also commenced as long ago as 1878, carried on for six or seven years and then dropped. I hope, however, at no remote date, to bring this forward to the present time.

On taking charge of the library I was at once impressed with the immense value of the periodical literature on our shelves and the great importance of making it more readily accessible, and have had in contemplation for some time the beginning of a card index to all our periodicals on the same general plan as that of Rieth's Repertorium. I have, however, been unable to obtain sufficient force to cover the whole ground, but have selected about one hundred and fifty journals, notably those upon the subjects of chemistry, electricity and engineering, both in English and foreign languages, the indexing of which has been in progress since the first of January. This number includes substantially all the valuable material in our possession in the English language, not only journals, but transactions of societies, all the electrical journals and nearly all the chemical in foreign languages. This index will be kept open to the public as soon as sufficient material has accumulated. In general plan it will be alphabetical, following very nearly the arrangement of the periodical portion of the Surgeon-General's catalogue. I shall depart from the strictly alphabetical plan sufficiently to group under such important subjects as chemistry, electricity, engineering, railroads, etc., all the subdivisions of the art, so that the electrical investigator, for instance, will not be obliged to travel from one end of the alphabet to the other to find the divisions of generators, conductors, dynamos, telephones, telegraphs, etc., and in the grouping of the classes of applied science the office classification of inventions will, as a rule, be adhered to, the subdivisions being, of course, arranged in alphabetical order under their general head and the title of the several articles also arranged alphabetically by authors or principal words.

With many thanks for the kind interest and valuable information afforded me, I remain,

Very truly yours,

HOWARD L. PRINCE,
Librarian Scientific Library.

The committee much prefers to record completed work than to mention projects, as the latter sometimes fail. It is satisfactory,

however, to announce that the indefatigable indexer, Dr. Alfred Tuckerman, is engaged on an extensive Bibliography of Mineral Waters. The Chairman of the Committee expects to complete the MS. of a Select Bibliography of Chemistry during the year, visiting the chief libraries of Europe for the purpose this summer.

H. Carrington Bolton, *Chairman*,
F. W. Clarke,
Albert R. Leeds,
Alexis A. Julien,
John W. Langley,
Albert B. Prescott.

[Dr. Alfred Tuckerman was added to the committee at the Washington meeting to fill the vacancy].

Report of the Committee on Spelling and Pronunciation of Chemical Terms.

During the past four years, your committee has sought to obtain from the members of this Section, from leading American Philologists, and from American Chemists in general, an exhaustive and thoroughly representative expression of opinion on the questions coming within the scope of its commission, which has been essentially the attainment of uniformity in the orthography and pronunciation of the terms used in our science.

Three preliminary reports were distributed to American Chemists in the years 1889, 1890 and 1891, inviting extended criticism and suggestion.

The substance of the replies to these was carefully digested and submitted to the Chemical Section each year for detailed discussion and decision.

The present and final report of your committee embodies the results of these four years of correspondence and discussion, as completed by the sectional action at the present meeting of the Association. It is presented in the hope that all chemists, especially those engaged in teaching, will cordially unite in the effort to bring about the desired uniformity in usage.

The reasons for the adoption of a few more radical changes in our nomenclature are to be found in the report for 1890. Those specially interested in the subject who have not attended the recent sessions of the Association may freely correspond with individual members of the Committee, who will gladly furnish more detailed explanation of the principles involved.

The following summary of rules is not to be regarded as final. Your committee recognize the fact that after a fair trial for a decade or even less, certain modifications will in all probability be generally regarded as desirable.

In conclusion the committee express their sincere thanks to their many colleagues throughout the land, who have so promptly and fully responded to the successive requests for data, suggestions and opinions.

T. H. Norton,
Edward Hart,
H. Carrington Bolton,
Jas. Lewis Howe.

RULES FOR THE ORTHOGRAPHY AND PRONUNCIATION OF CHEMICAL TERMS.

GENERAL PRINCIPLES OF PRONUNCIATION.

1. The pronunciation is as much in accord with the analogy of the English language as possible.
2. Derivatives retain as far as possible the accent and pronunciation of the root word.
3. Distinctly chemical compound words retain the accent and pronunciation of each portion.
4. Similarly sounding endings for dissimilar compounds are avoided (hence -**ĭd**, -**īte**).

ACCENT.

In polysyllabic chemical words the accent is generally on the antepenult; in words where the vowel of the penult is followed by two consonants, and in all words ending in **-ic** the accent is on the penult.

PREFIXES.

All prefixes in strictly chemical words are regarded as parts of compound words, and retain their own pronunciation unchanged (as, ă′ceto-, ă′mĭdo-, ă′zo-, hȳ′dro-, ī′so-, nī′tro-, nĭtrō′so-).

ELEMENTS.

In words ending in **-ium**, the vowel of the antepenult is short if **i** (as **īrĭ′dium**), or **y** (as **dĭdў′mium**, or if before two consonants (as **că′lcium**), but long otherwise (as **tĭtā′nium**, **sĕlē′nium**, **chrō′mium**).

al′ūminum	chrō′mium	ī′ōdĭn	nī′trogen
a′ntimony	cō′balt	īrĭ′dium	ŏ′smium
a′rsĕnic	colŭ′mbium	iron	ŏ′xygen
bā′rium	co′pper	lă′nthanum	pallā′dium
bi′smuth (biz)	dĭdў′mium	lead	phŏ′sphorus
bō′ron	e′rbium	lĭ′thium	plă′tinum
brō′mĭn	flū′orĭn	magnē′sium (zhium)	potă′ssium
că′dmium	gă′llium	ma′nganese (eze)	rhō′dium
că′lcium	germā′nium	me′rcury	rubĭ′dium
ca′rbon	glū′cinum	mō′lўbdenum	ruthē′nium
cē′rium	gold	nĭ′ckel	samā′rium
cē′sium	hȳ′drogen	nĭ′obium	scă′ndium
chlō′rĭn	ĭ′ndium	nī′ckel	sĕlē′nium

Fāte, făt, fär, mēte, mĕt, pīne, pĭn, marîne, nōte, nŏt, möve, tūbe, tŭb, rüle, mȳ, ў = ĭ.

′ Primary accent; ″ secondary accent. N. B. The accent follows the vowel of the syllable upon which the stress falls, but does not indicate the division of the word into syllables.

silicon	sŭ'lfur	thō'rium	vănā'dium
silver	tă'ntalum	tin	ytte'rbium
sō dium	tellū'rium	tĭtā'nium	ў'ttrium
strŏ'ntium	te'rbium	tŭ'ngsten	zinc
(shium)	thă'llium	ūrā'nium	zircō'nium

Also: ămmō'nium, phosphō'nium, hă'logen, cў ă'nogen, ămĭ'dogen.

Note in the above list the spelling of the halogens, cesium and sulfur; **f** is used in the place of **ph** in all derivatives of sulfur (as sulfuric, sulfite, sulfo-, etc.).

TERMINATIONS IN -ic.

The vowel of the penult in polysyllables is short (as cў ă'nic, fūmă'ric, arsĕ'nic, silĭ'cic, iō'dic, būtў'ric), except (1) **u** when not before two consonants (as mercū'ric, prŭ'ssic), and (2) when the penult ends in a vowel (as benzō'ic, olē'ic); in dissyllables it is long except before two consonants (as bō'ric, cĭ'tric).

Exceptions: acē'tic or acĕ'tic.

The termination **-ic** is used for metals only where there is a contrast with **-ous** (thus avoid aluminic, ammonic, etc.).

TERMINATIONS IN -ous.

The accent follows the general rule (as plă'tinous, sŭ'lfurous, phŏ'sphorous, coba'ltous). Exception: acē'tous.

TERMINATIONS IN -ate AND -ite.

The accent follows the general rule (as ă'cetāte, vă'nadāte); in the following words the accent is thrown back (as ă'bietāte, ă'lcoholāte, ă'cetonāte, ă'ntimonīte).

TERMINATIONS IN -id (FORMERLY -ide).

The final **e** is dropped in every case and the syllable pronounced **-ĭd** (as chlō'rīd, ī'odīd, hў'drīd, ŏ'xĭd, hў drŏ'xĭd, sŭ'lfĭd, ă'mĭd, ă'nilīd, mūrĕ'xĭd).

TERMINATIONS IN -ane, -ene, -ine and -one.

The vowel of these syllables is invariably long (as mĕ'thāne, ĕ'thāne, na'phthalēne, a'nthracēne, prō'pīne, quĭ'nōne, ă'cetōne, kē'tōne).

A few dissyllables have no distinct accent (as benzēne, xўlēne, cētēne).

Fāte, făt, făr, mēte, mĕt, pīne, pĭn, marîne, nōte, nŏt, mŏve, tūbe, tŭb, rüle, mў, ў = ĭ.

' Primary accent; "secondary accent. N. B. The accent follows the vowel of the syllable upon which the stress falls, but does not indicate the division of the word into syllables.

The termination **-ine** is used only in the case of doubly unsaturated hydrocarbons, according to Hofmann's grouping.

TERMINATIONS IN **-in.**

In names of chemical elements and compounds of this class, which includes all those formerly ending in **-ine** (except doubly unsaturated hydrocarbons) the final **e** is dropped, and the syllable pronounced -ĭn (as chlō′rĭn, brō′mĭn, etc., ă′mĭn, ă′nilĭn, mo′rphĭn, quĭ′nĭn, vanĭ′llĭn, alloxă′ntĭn, absi′nthĭn, emŭ′lsĭn, că′ffeĭn, cō′caĭn).

TERMINATIONS IN **-ol.**

This termination, in the case of specific chemical compounds, is used *exclusively* for alcohols, and when so used is never followed by a final **e**. The last syllable is pronounced -ōl (as glȳ′cōl, phē′nōl, crē′sōl, thȳ′mōl (ti), glȳ′cerōl, quĭ′nōl).

Exceptions: ălcohŏl, a′rgŏl.

TERMINATIONS IN **-ole.**

This termination is always pronounced -ōle and its use is limited to compounds, which are not alcohols (as ĭ′ndōle).

TERMINATIONS IN **-yl.**

No final **e** is used; the syllable is pronounced -ĭl (as ă′cetĭl, ă′mĭl, cē′rotĭl, cē′tĭl, ĕ′thĭl).

TERMINATIONS IN **-yde.**

The **y** is long (as ă′ldehīdė).

TERMINATIONS IN **-meter.**

The accent follows the general rule (as hydrŏ′meter, barŏ′meter, lactŏ′meter).

Exception: words of this class used in the metric system are regarded as compound words, and each portion retains its own accent (as cĕntime″ter, mi′llime″ter, kĭ′lome″ter).

MISCELLANEOUS WORDS

which do not fall under the preceding rules.

Note the spelling: albumen, albuminous, albuminiferous, asbestos, gramme, radical.

Note the pronunciation: a′lkaline, a′lloy (n. & v.) a′llotropy, a′llotropism, ĭ′somerism, pŏ′lymerism, apparā′tus (sing.

Fāte, făt, fär, mēte, mĕt, pine, pĭn, marîne, nōte, nŏt, möve, tūbe, tŭb, rüle, mȳ, ў = ĭ.

′ Primary accent; ″ secondary accent. N. B. The accent follows the vowel of the syllable upon which the stress falls, but does not indicate the division of the word into syllables.

& plu.), āqua regia, barȳ′ta, cĕntigrade, co′ncentrated, crystallĭn or crystalline, electrŏ′lysis, lîter, mŏ′lecule, mŏlĕ′cular, nō′menclā″ture, olē′fiant, qua′ntivā″lence, vā′lence, ŭ′nivā″lent, bī′vā″lent, trī′vā″lent, qua′drivā″-lent, tī′trate.

A LIST OF WORDS WHOSE USE SHOULD BE AVOIDED IN FAVOR OF THE ACCOMPANYING SYNONYMS.

For	Use
beryllium	glucinum
niobium	columbium
thein	caffein
titer (n.)	strength or standard
titer (v.)	titrate
monovalent	univalent
divalent, etc.	bivalent, etc.
quantivalence	valence
sodic, calcic, zincic, nickelic, etc. chlorid, etc.	sodium, calcium, zinc, nickel, etc. chlorid, etc. vid. terminations in -ic supra.
arsenetted hydrogen	arsin
antimonetted hydrogen	stibin
phosphoretted hydrogen	phosphin
sulfuretted hydrogen, etc.	hydrogen sulfid, etc.
alkylogens	alkyl haloids
benzol	benzene
toluol, etc.	toluene, etc.
pyrocatechin	catechol
resorcin	resorcinol
*hydroquinone (and hydrochinon)	quinol
orcin	orcinol
hydrophlorone	phlorol
phloroglucin	phloroglucol
quercite	quercitol
pinite	pinitol
glycerin	glycerol
erythrite, erythroglucin, eryglucin, erythromannite, phycite	erythrol

* Regarding this and the following words, cf. J. Chem. Soc. XLI, p. 248.

Fāte, făt, fār, mēte, mĕt, pīne, pĭn, marîne, nōte, nŏt, möve, tūbe, tŭb, rüle, mȳ, ў = ĭ.

′ Primary accent; ″ secondary accent. N. B. The accent follows the vowel of the syllable upon which the stress falls, but does not indicate the division of the word into syllables.

mannite	mannitol
dulcite	dulcitol
sorbite	sorbitol
furfurol	furfuraldehyde
fucusol	fucusaldehyde
anisol	methyl phenate
phenetol	ethyl phenate
anethol	methyl allyl-phenol

NOTE: It has been suggested that the words qualitative and quantitative could be advantageously replaced by qualitive and quantitive, deriving the terms from the Latin adjectives instead of the nouns, as has been done in the case of rotary instead of rotatory, agriculturist instead of agriculturalist, etc. The Section regards this change as eminently desirable, but on account of the extended use of the words outside of chemistry, delays action until the opinions of those in allied branches have been obtained.

Fāte, făt, fär, mēte, mĕt, pīne, pĭn, marîne, nōte, nŏt, mōve, tūbe, tŭb, rüle, mў̄, ў̆ = ĭ.

ˈPrimary accent; ˈˈsecondary accent. N. B. The accent follows the vowel of the syllable upon which the stress falls, but does not indicate the division of the word into syllables.

BIBLIOGRAPHY OF RECENT WORK ON CHEMICAL NOMENCLATURE AND PRONUNCIATION.

Reports of the Committee on Spelling and Pronunciation of Chemical Terms. Proceedings of the American Association for the Advancement of Science, 1889, 1890, 1891.

Reports of the Committee appointed for the purpose of drawing up a statement of the varieties of Chemical Names which have come into use, for indicating the causes which have led to their adoption, and for considering what can be done to bring about some convergence of the views on Chemical Nomenclature obtaining among English and Foreign Chemists. Proceedings of the British Association for the Advancement of Science, 1883, 1884 and 1885.

Instructions to Abstractors on Nomenclature and Notation. Jour. Chem. Soc., 58, p. 53 (1890).

Report of the Committee on Nomenclature and Notation. Journal of the American Chemical Society, 8, 116 (1886).

Report of the Committee on a National Chemical Society.

Prof. F. W. Clarke reported, on behalf of the Committee, that a conference of representatives of ten organizations had been held. The representatives of the American Chemical Society had indicated a willingness to make the changes in their constitution necessary to adapt it to the requirements of American chemists in general, and a unanimous vote of all delegates present favored a union under the charter of that body.

The committee, having completed its work, was at its own request discharged.

PAPERS READ.

GABBRO PHONOLYTE. By Dr. E. GOLDSMITH, 658 N. 10th street, Philadelphia, Penn.

[ABSTRACT.]

IN Bucks county, on the slope of Haycock mountain, and in Montgomery county, on the top of Ringing hill, there are deposits of igneous plutonic boulders and slabs known to geologists generally, as "Trap."

The deposit, as found on Haycock mountain, lies about ten miles east of Quakertown, in Bucks county, and that on Ringing hill is about three miles north of Pottstown, Montgomery county. In Bucks county the deposit is called by the people "Stony Garden," because of the trees growing around and, seemingly, encroaching upon it.

A similar condition exists with reference to the Montgomery county deposit. These klinkstones, as they are called (or, more properly speaking, phonolyte), produce a metallic sound, when struck by a hammer or fragment of the same rock, and this sound differs with almost every block or slab. It is known that these deposits are basic rocks and this fact was fully substantiated by my having, in a careful examination of some specimens, obtained 52.15% of silica (Si). It is impossible to determine, macroscopically, the mineral species represented by this Phonolytic deposit. It is, generally, fine-grained and sometimes, with the aid of a pocket lens, a few crystals can be discerned; these, however, are not well defined and they are not visible without the aid of a microscope. The results obtained from this examination were, essentially, plagioclastic feldspar, diallage and magnetite, the latter containing, possibly, some titanic acid. Inasmuch as the composition embodied in these deposits constitute a gabbro, I have proposed as the name for this, the first American Phonolyte, GABBRO PHONOLYTE.

RAPHIDES, THE CAUSE OF THE ACRIDITY OF CERTAIN PLANTS. By Prof. H. A. WEBER, Ohio State University, Columbus, Ohio.

[ABSTRACT.]

THE writer shows conclusively, that the acridity of the Indian turnip and *Calla cassia* is due to the presence of raphides of calcium oxalate only. The reason why other plants, as the fuchsia and tradescantia, which also

are full of raphides of the same form and composition, are not acrid, is shown to be due to the fact, that in the latter plants the raphides are embedded in an insoluble mucilage, whereby the free movement of the crystals is prevented.

TRI-NITRO TOLUENE, A SUBSTITUTE FOR MUSK. By WM. H. SEAMAN, Washington, D. C.

[ABSTRACT.]

SPECIMENS of Ludwig Mond's nickel carbon monoxide, and Albert Baur's tri-nitro-toluene, or musk substitute, were exhibited and described. The first is the subject of United States patents, Nos. 455, 227, and 455, 229, dated June 30, 1891. The latter forms the subject matter of patents of Schnaufer and Hupfeld, Nos. 412, 545, Oct. 8, 1889, and of Nos. 416, 710, Dec. 10, 1889, and 451, 847 to Albert Baur, dated May 5, 1891.

THE INFLUENCE OF NEGATIVE ATOMS AND GROUPS OF ATOMS ON ORGANIC COMPOUNDS. By Prof. PAUL C. FREER, Ann Arbor, Mich.

[ABSTRACT.]

THE fact that the substitution of negative elements or groups for hydrogen in organic compounds, can render neutral bodies acid in their nature has long been known, and numerous instances of such a modification of properties can be cited, but, as yet, few attempts have been made to measure this influence in such a manner that comparisons could be instituted. The conclusions arrived at by a series of experiments in organic, would, undoubtedly, be of the greatest value in a comprehension of inorganic chemistry. In 1879, Menschutkin published his study of the Influence of Isomerism on the Etherification of Alcohols and Acids, he first using a definite acid, while changing the alcohol, and then varying the acid, leaving the alcohol unchanged. This investigator mixed equivalent weights of alcohol and acid and heated in sealed flasks; determining by titration the amount of acid remaining unchanged. By heating a number of flasks at the same time, and removing one after another, he was able to study the initial rate and final boundary of etherification. Mr. D. M. Lichty and I employed similar methods in the following research, some important modifications being introduced, owing to the nature of the acids employed. The acids chosen were mono-, di-, and tri-chloroacetic acids and monobromoacetic acid; the alcohol, ethyl alcohol. The more negative the grouping of elements composing an acid is made, the more pronouncedly acid should the body be, so that mono-chlor-acetic acid should display greater avidity than acetic acid. The results of the work, which will be continued with a large number of acids, have been as follows. With acetic acid and

ethyl alcohol, Menschutkin found that after one hour 47.34 per cent of the acid was changed to ether while after twenty-four hours 66.01 per cent was changed. With mono-chloroacetic acid we found 66.62 per cent etherified after one hour; with di-chloroacetic acid 70.65 per cent; with mono-bromo-acetic acid 62.67 per cent. These results agree with theory although, it will be seen, the second chlorine atom exercises much less influence, comparatively, than did the first. No data were as yet obtained for tri-chloro-acetic acid, because the latter decomposed at the temperature used. The limit of etherification in these negative acids is practically reached within the first hour, they thus differing markedly from acetic acid. The greatest care was taken to purify the alcohol and acids used, some new methods of purification were employed and important modifications of Menschutkin's methods introduced. It was furthermore found that these chlorinated acids saponify with great rapidity and a research on the rapidity of saponification has been begun. The limits of this abstract do not permit of the description of any of the details.

A LATENT CHARACTERISTIC OF ALUMINUM. By Dr. ALFRED SPRINGER, Box 621, Cincinnati, Ohio.

[ABSTRACT.]

THE discovery relates to sound boards of stringed musical instruments, its object being to produce an instrument of more sonorous and pleasing tone qualities than those commonly in use.

I have discovered in Aluminum a latent quality which adapts it in a remarkable degree to use in the construction of sounding-boards, and that it differs from all other metals, so far as I am aware, in the absence of comparatively continuous and uniform higher partial tones which give the tone-color called "metallic," and, further, that it also possesses an elasticity capable of sympathetic vibration uniformly through a wide range of tone-pitch, which renders it in this respect superior to wood.

It will be readily understood that, apart from the improved tone-qualities obtained from the use of this metal, it possesses certain advantages over wood in its incombustibility, impermeability to moisture, and comparative freedom from the liability to injury, such as splitting, etc., to which wooden instruments are subject.

The thickness of the sheet may be so reduced as to obtain the utmost amplitude of tone vibration without injury to the quality of tone produced, in which respect this metal is superior for the purpose to either wood or to other metals.

ON THE DELICACY OF THE TESTS FOR PHENOL. By Prof. JOHN G. SPENZER, 368 Central Ave., Cleveland, Ohio.

[ABSTRACT.]

THE discrepancy in the authoritative statements on the sensitiveness of the more important tests for phenol is well known.

Almén and Pollucci have both studied this; the results obtained, however, are widely different.

The present paper contains a more extended list than either of the preceding authorities have made.

The original and modifications of tests have been tried alike and results of each given. For colorimeters flint glass flat-bottomed tubes were cemented to strips of wood covered with dead-white paper; in this manner colorimetric trains of any desired length were made, with a saving of much time.

Transmitted or direct, natural and artificial light aided by black and white paper, according to which gave the more satisfactory results, were used.

A phenol in loose, dry crystals having a melting point of 33.5° C. and a congealing point of 38.95° C. was accepted as a standard from four samples examined.

Previous to determining the melting and congealing points with an accurate $\frac{1}{10}$° C. thermometer the phenol was boiled to remove any trace of moisture, which it might contain.

THE TESTS.

*Author's limitation of tests.

1. Ferric chloride neutral solution (Runge).

The test is obliterated or retarded by excess of the reagent, traces of acid or ammonia (Neubauer und Vogel Hamairalyse); presence of alcohol (Hesse, *Ibid*).

No reaction takes place in very dilute aqueous solution (Sarauw).

Alcoholic phenol gives with alcoholic ferric chloride a reaction (Frisch).

Aqueous acid, aqueous neutral; alcoholic acid and alcoholic neutral test solutions tried, all gave reaction equally sensitive; the alcoholic solutions gave more permanent reactions.

Delicacy: Pollucci, 2000; Almen, 3000; * 2500.

2. Ferric sulphate (Dragendorff). Delicacy: Dragendorff, 2000; *900.

3. *a* Heated with ordinary HNO_3, yellow coloration; *b* Supersaturated with NaOH, brownish yellow. Delicacy: *a* Pollucci, 6000; **a*, 50,000; *b*, 700,000.

4. *a* HCl, phenol and HNO_3 (Allen); *b* Supersaturating with NaOH, dark brown. Delicacy: **a*, 25,000; *b*, 80,000.

5. *a* Sulpho-molybdic acid (Davy's solution); *b* Sulpho-molybdic acid (Froehde's solution). Delicacy: **a*, 15,500; *b*, 15,500.

6. *a* Bromine water (Landolt); *b* Bromine vapor (Jacobson). Delicacy: *a* Almen, 60,000; Pollucci, 15,000; Landolt, 57,100; Cloetta and Schær, 100,000; *125,000; *b* Jacobson, 40,000; *75,000.

7. Millon's Reagent: *a* (1) Boil phenol solution with excess mercuric, nitrate, add KNO_2 (1-10); *a* (2) Phenol, mercuric nitrate, KNO_2 (1-10). boil; *a* (3) Phenol, mercuric nitrate, KNO_2 (1-10), in cold. *b* Phenol, 5-10 drops Millon's Reagent, boil, drop in HNO_3, fuming sufficient (Almen). *c* Phenol, mercurous nitrate, trace of HNO_3, boil (Plugge) *d* Phenol mercuric nitrate, HNO_3, in cold (Dragendorff). Delicacy: *a* (1)

Almen, 200,000; *400,000; *a* (2) *400,000; *a* (3) *400,000; *b* Almen, 2,000,000; *2,000,000; *c* Plugge, 60,000; *65,000; *d* Dragendorff, 100,000; *100,000.

8. *a* Phenol (NH_4)OH, $CaCl_2O_2$ (Lex); b_4 Phenol (NH_4)OH, Bromine vapor (Flueckiger); b_2 Phenol (NH_4)OH, Bromine water (Allen). Delicacy: *a* Almen, 50,000; Pollucci, 3,000; Dragendorff, 10,000; *100,000. *b* (1) *15,000; *b* (2) *30,000.

9. *a* Jacquemin's Aniline Test; *b* Jacquemin's Aniline Test, Dragendorff's modification; *c* Jacquemin's Aniline Test, Allen's version; *d* Jacquemin's Aniline Test, Cotton's modification. Delicacy: *a* Pollucci, 66,000; *b* *2,000,000; *c* *2,000,000; *d* *500,000.

10. Phenol, conc. H_2SO_4 and KNO_3 (Hoffman). Delicacy: *65,000.

11. $KClO_3$ HCl, (NH_4)OH and Phenol (Rice). Delicacy: Dragendorff, 12,000; *20,000.

12. Phenol and sodium nitroprusside. Delicacy: *30,000.

The following tests were omitted having been found faulty or unsuitable:

13. The H_2SO_4 and KNO_2 test of Liebermann.
14. Alcoholic phenol and (NH_4)OH (Phipson).
15. KHO and chloroformic phenol (Crump).
16. Phenol alkalies and chloroform (Guareschi).
17. Soluble carbolates and pinewood (Lemaire).

The widely differing results obtained by some the writer thinks is due to hastiness or want of thoroughness in applying the tests.

THE CHEMISTRY OF SOME DISEASE GERMS. By Dr. E. A. v. SCHWEINITZ, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE paper gave a brief description of the chemical products of the swine plague germs; their difference from those of the hog cholera and other germs, with the practical application and use of the former for the prevention of disease.

DISTRIBUTION OF TITANIC OXIDE ON THE EARTH'S SURFACE. By Prof. F. P. DUNNINGTON, University of Virginia.

[ABSTRACT.]

THIS paper presents the results of examining for titanic oxide. Specimens of soil, together with some typical rocks taken from widely separated points upon the earth's surface. Samples were obtained from fifteen states, Sandwich Islands, Japan, China, India, Russia, Prussia and Great Britain. The results are given for eighty specimens, and in no case is

titanic oxide wholly absent. The alluvial soils, in a measure, representing the average composition of large areas of rock, usually contain from .5 to .7 per cent of titanic oxide. In some sedentary soils the amount is not unfrequently as much as 3 and even 6 per cent.

BIOLOGICAL FUNCTION OF THE LECITHINES. By Dr. WALTER MAXWELL, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

IN a paper presented before the Association in 1890, it was shown that during the initial stages of plant growth, the phosphorus contained in the mature seed as a mineral phosphate, under the action of the process of germination, becomes separated from the inorganic compound and re-appears in the organism of the young plantlet in an organic form as lecithine, and that the lecithines form a medium through which the element phosphorus passes from the mineral to the vegetable kingdom.

A continuance of the study of the function of the lecithines, which has been conducted with the normal hen's egg, and the incubation products of the egg have indicated that the phosphorus contained in the egg in the organic form as a lecithine, under the action of the process of incubation, becomes eliminated from the lecithine compound and re-appears in the mineral form as a phosphate, and is utilized in the formation of animal bone.

It thus appears that the lecithine bodies are a medium through which the circulation of the element phosphorus is conducted, passing from the mineral, through the vegetable, and into the animal kingdom.

SYNTHESIS OF WEIGHED QUANTITIES OF WATER FROM WEIGHED QUANTITIES OF OXYGEN AND HYDROGEN GASES. By Prof. EDWARD W. MORLEY, 749 Republic St., Cleveland, O.

[ABSTRACT.]

FOUR series of determinations of the atomic weight of oxygen have been made by a process in which about thirty-four grammes of water have been produced in each experiment from corresponding quantities of hydrogen and oxygen gases.

The hydrogen was weighed as absorbed by palladium, a method first suggested and made the subject of experiment by the writer. The oxygen was weighed in globes counterpoised as in Regnault's method but all the weighings were by the method of reversals. A weighing cave has been constructed containing an apparatus which holds three pairs of objects, either of which pairs can be suspended from the balance standing above

the cave and quickly reversed. Each pair has its own pan and weights; the reversals and weighings can therefore be made from a distance, without opening the cave or balance case.

The apparatus in which the combustions were made consisted of a glass tube, containing two platinum jets for introducing the gases, and points for the passage of sparks for beginning the combustion. This apparatus was weighed while exhausted and closed by fusion. Then it was opened (without admitting moisture), connected to the sources of oxygen and hydrogen by tubes containing stopcocks and pressure gauges, and exhausted. It was surrounded with water, in part, and in part by a freezing mixture. The gases were admitted and ignited, and the admission regulated by the indications of the three pressure gauges. When the combustion was discontinued, the gases remaining in the apparatus were removed by means of a Toepler pump, and collected for measurement and analysis. The combustion apparatus containing the water produced was closed by fusion and weighed; the palladium tube was closed by fusion and weighed; the globes for oxygen were in some experiments closed by turning the key of their stopcocks, and in some, by fusion.

The experiments so far made divide themselves into four series, though the whole number of experiments is only eleven. In series first, there were used one globe of oxygen and two tubes for the palladium; in the second, two globes and two tubes; in the third, two globes and one tube containing all my palladium; in the fourth, the globes had fusible metal valves. The palladium tubes always had fusible metal valves; I had some twenty stopcocks, but could not select one which would not leak, and even a slight leakage here would be fatal to accuracy.

The mean results of these four series are: 15.878^2, 15.879, 15.879^2, 15.879, with a mean error of a single experiment of .0013 or $\frac{1}{1200}$.

NOTES ON PINITE. By Prof. H. W. WILEY, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

SHOWS further oxidation products of pinite and especially some crystalline forms of rhodozonic acid.

NOTE ON CHEMICAL COMPOSITION OF MUCK SOIL FROM FLORIDA. By Prof. H. W. WILEY, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

SHOWS percentage of volatile and organic matter in soils, percentages of carbon and hydrogen in the dried soil, percentage of nitrogen, absorptive power of soils, etc; also variations in composition of the muck taken at different depths and chemical changes in soil due to cultivation.

COMPOSITION OF CRYSTALLINE ARTIFICIAL CALCIUM PHOSPHATE. By Prof. H. W. WILEY, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

GIVES results of analyses of two kinds of crystals found in slag from furnaces operated in the basic process for manufacture of steel.

MEAT PRESERVATIVES. By I. THOMAS DAVIS, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

GIVES results of investigations on preservatives used in canned meats, together with a study of the best processes for identifying them and determining them by analytical processes.

DETERMINATION OF IRON AND ALUMINA IN THE PRESENCE OF PHOSPHORIC ACID. By W. H. KRUG, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

GIVES an account of the various methods in use for determining iron and alumina in presence of P_2O_5 and especially of Glaser's method and points out the sources of error. Gives also an accurate method of exactly determining the phosphoric acid in the conditions named.

NOTE ON COMPOSITION OF FLORIDITE. By Prof. H. W. WILEY and W. H. KRUG, U. S. Dept. of Agriculture, Washington, D. C.

[ABSTRACT.]

GIVES chemical analyses of samples of Florida phosphates, named floridite by Prof. E. T. Cox. Complete analyses are given and the claims of the samples to be considered a mineral species considered.

DI-NITRO-SULPHO-PHENOL. By Prof. EDWARD HART, Easton, Pa.

[ABSTRACT.]

WHEN para-sulfo-phenol is treated with nitric acid a dinitro-para-sulfo-phenol is formed which is probably new. The most important application of this discovery lies in its connection with the manufacture of picric acid.

[This paper will be printed in the Journal of Analytical and Applied Chemistry.]

CONTINUOUS FEED APPARATUS FOR DISTILLING WATER. By Prof. W. M. STINE, Ohio University, Athens, Ohio.

[ABSTRACT.]

THE paper deals with a modification of the usual type of apparatus for the distillation of water; the design being to render this self-feeding and to some extent automatic in its action. A siphon feed-pipe introduced between the condenser and boiler, passes the hot water from the condenser coils back to the boiler. Two objects are accomplished,—a saving of considerable heat energy, and the purification of the feed water from scale and gaseous constituents, before admission to the evaporator.

[This paper is printed in the Scientific American Supplement for Aug. 22, 1891.]

FIRE CLAY FROM MOUNT SAVAGE, MARYLAND. By Dr. LEONARD P. KINNICUTT, Worcester Polytechnic Institute, Worcester, Mass.

[ABSTRACT.]

THIS clay occurs in the carboniferous in veins 7–14 feet thick. It is of a dark gray color with bright polished surfaces. It is very hard and has a concoidal fracture, and a structure as though formed by volcanic action. The clay is almost infusible before the blow-pipe and has the specific gravity of 2.54. The analysis shows that it does not contain any feldspar or other double silicates, and that it has the following composition:

Water,	9.88
Silicate of aluminum,	57.19
Sand, or free silica,	31.84
Hydrated silica,	0.23
Per oxide of iron,	0.89
Magnesia,	Trace
Titanium oxide,	Trace
Alkalies,	0.03
Carbon,	0.02
	100.08

Allowing that the water, silica and alumina are united chemically we have as the composition of the hydrated silicate of aluminum:

Silica,	42.08
Alumina,	45.22
Water,	14.70

which corresponds closely to the formula $2Al_2O_3$, $3SiO_2$, $4H_2O$.

IMITATION COFFEES. By G. L. SPENCER and E. E. EWELL, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

GIVES an account of the analyses of artificial and imitation coffees, and the means of detecting adulterations of coffees. Data and analyses are given.

THE ATOMIC THEORY. By C. L. SPEYERS, Rutgers College, New Brunswick, N. J.

[ABSTRACT.]

As a substitute for the indivisible atomic conception of matter, a theory is offered based upon the principles that:—

1. Electricity is interwoven with matter-texture. Though differing with the elements in quantity and potential, the total amount in a unit mass of each element is fixed, but the relative quantity of positive and negative electricity can vary. Within very small, but finite distances, these electric changes attract and repel according to Coulomb's Law.

Accordingly, an element is to be defined as matter in which the ratio of mass to electricity is fixed for that element. When that ratio is disturbed the element is changed, namely in ferrous and ferric iron, -ous and -ic mercury, etc.

2. The energy required to move a unit of electricity, a unit distance, through a unit section, varies with the elements; that is, each element has a different internal conductivity.

In metallic matter, the electricity meets with little resistance to motion, but in non-metallic matter, non-conductors and forming negative ions, with great opposition.

3. Chemical affinity is electrical attraction and its mode of action is expressed by Coulomb's Law.

With these three principles an attempt is made to account for chemical action as expressed by the Laws of Definite and Multiple Ratio. Numerical relations have not yet been deduced.

AN INQUIRY RELATIVE TO THE CAUSES LEADING TO THE FORMATION OF ORE DEPOSITS. By W. ALBERT CHAPMAN, Yellville, Marion Co., Ark.

A CONVENIENT ARRANGEMENT FOR A PASTEUR FILTER WHERE AIR-PRESSURE IS AVAILABLE. By Dr. E. A. v. SCHWEINITZ, U. S. Department of Agriculture, Washington, D. C.

PRELIMINARY NOTES ON THE INFLUENCE OF SWAMP WATER IN THE FORMATION OF THE PHOSPHATE NODULES OF SOUTH CAROLINA. By Prof. CHARLES L. REESE, Charleston, S. C.

THE CALCULATION OF THE BOILING POINT OF PARAFFIN UNDER ANY PRESSURE. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[To be printed in Zeits. für physikal. Chem., Leipzig.]

THE CALCULATION OF THE BOILING POINTS OF ISOMERICS FROM THEIR MOMENT OF INERTIA. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[To be printed in Comptes Rendus, Paris.]

DETERMINATION OF THE TRUE POSITION OF CARBON ATOMS IN ORGANIC COMPOUNDS BY MEANS OF ANALYTICAL MECHANICS. By Dr. GUSTAVUS HINRICHS, St. Louis, Mo.

[Printed in Comptes Rendus, Paris.]

LAND AND RIVER PHOSPHATE PEBBLES OR NODULES OF FLORIDA. By Prof. E. T. Cox, 10 Wall St., New York, N. Y.

ON PLATTNERITE FROM IDAHO. By Dr. W. S. YEATES, U. S. National Museum, Washington, D. C.

THE PRECIPITATION OF FISH OIL IN LINSEED OIL, WHEN USED AS AN ADULTERANT, BY SOLUTION OF NITRATE OF SILVER. By THOMAS TAYLOR, M.D., U. S. Department of Agriculture, Washington, D. C.

THE SEPARATION AND PRECIPITATION OF LINOLEIN FROM LINSEED OIL, BY NITRATE OF SILVER. By THOMAS TAYLOR, M.D., U. S. Department of Agriculture, Washington, D. C.

PURIFICATION OF WORCESTER SEWAGE BY CHEMICAL PRECIPITATION. By Dr. LEONARD KINNICUTT, Polytechnic Institute, Worcester, Mass.

AN ACETOACITIC ETHER. By Dr. J. N. NEF, Worcester, Mass.

SECTION D.

MECHANICAL SCIENCE

AND

ENGINEERING.

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ADDRESS

BY

PROFESSOR THOMAS GRAY.

VICE-PRESIDENT, SECTION D.

PROBLEMS IN MECHANICAL SCIENCE.

This section of the American Association for the Advancement of Science devotes its attention to the department which was defined by Rankins as "that branch of knowledge which enables its possessor to plan a structure or machine for a given purpose without the necessity of copying an existent example; to compute the theoretical limit of the strength and stability of a structure, or the efficiency of a machine of a particular kind; and to judge how far an existent practical rule is founded on reason, how far on custom and how far on error." Since that definition was given, great additions have been made to the knowledge requisite for its fulfilment; but each addition to our knowledge only points to the need for further work. The application of mechanical science to engineering has brought about considerable changes in the methods of designing structures and machines and has at the same time given rise to much discussion, not only as to the best methods in engineering practice, but also as to the proper kind of education that should be given to those who propose to follow that profession. Comparatively few years ago there was nothing but the so-called practical education obtained by apprenticeship and in many cases, especially in civil engineering, obtainable only in return for considerable premiums. Engineers were slow to admit that a purely scientific body could be of much service to their profession and they objected strongly to the idea that an engineer could be taught in the same manner as a doctor of medicine or a lawyer, by the aid of college lectures.

The idea prevailed that scientific men bore pretty much the same relation to practical men that the old Greek theories of ideal perfect systems in astronomy bore to the actual facts observed. We have not as a matter of fact quite succeeded yet in breaking away from the notion that there is a possible ideal or theoretical science and a real or practical science, and that the man who approaches the subject of design from what we may call the mathematical side belongs to the ideal school, and may at any time propound a theory as absurd as the old one that circular motion is perfect, or that actual observation is a delusion because, as Hegel said, the planets are not pulled this way and that but move on their own account like blessed gods. It is needless for me to say here that modern science does not consider any ideal law as being celestial or terrestrial, perfect or imperfect, but turns its attention exclusively to what observation shows there is. Much of the exposition of science is no doubt interspersed with speculation but that part of the literature, no matter how valuable it may be in suggesting investigation, is not science and should never be indulged in when there is any chance of misinterpretation.

It is well to keep carefully in view that science is in its foundation essentially empirical and that therefore a scientific man is nothing if he is not practical. Science consists of classified knowledge of observed phenomena and the application of the laws derived therefrom. The point where we are apt to have speculation enter too freely is in the derivation of laws from the observed facts. Here comes the comparison of results of experiment and observation, the foreshadowing of a probable cause and the indication of a law of nature. It has to be kept in mind, however, that all such laws are to be tested in every possible way and are never to be considered as infallible. They are in reality generalizations from observed phenomena and must give way, or be modified, if they fail to account for any one observed result. It would be well if observers were always as anxious to disprove as to substantiate their theories, and as willing to record their failures as their successes when giving an account of their researches.

Science is, as I have said, classified knowledge; scientific method is the consistent observation of nature, not for the purpose of substantiating a preconceived theory but for the classification and comparison of the observations so as to deduce some rule or law in accordance with which these results might have been predicted.

It may be at once apparent that if such a law exist many other results would be obtained and the verification of these predictions is a valuable confirmation of the truth of the law. In the course of this work of verification it may become evident that some modification of the supposed law is required and it becomes necessary to see what modification will suit not only the old but the increased knowledge of facts. In this way laws of greater generality are obtained and these in their turn may be used to help on the search after a more and more complete knowledge of the why and wherefore of the occurrences and existences with which we are surrounded. If we look at our subject in this light we shall find less to criticise in the old method of conducting engineering work and also little reason why the modern method should be considered as essentially different from the old. The methods followed by practical engineers were not by any means wanting in the experimental element: in fact every new undertaking was an experiment and many valuable empirical rules were formed. The difference lay mainly in a want of systematic classification of the experience which had been gained and in the neglect of the available means of making systematic classification, namely, mathematical reasoning.

The applications of mathematics to practical problems had not been very generally studied: in fact mathematicians did not as a rule take much pride in the usefulness of their theorems. They wished their subject to remain what it had been for centuries, simply a means of sharpening the intellect, and to be studied simply as a mental discipline. As a matter of fact the utilitarian school is not popular yet with several of the most eminent of our mathematicians who still delight in problems of no interest to the common herd and rather consider it an honor to have produced nothing that can be understood by any but a few of their own disciples. Even those who stoop to waste their time on problems in applied mathematics appear to have great difficulty in shaking themselves clear of the purely imaginary and the exercises they give on the application of mathematical theorems are in most cases of a highly impractical character. If it be a matter merely of the difficulty of the problems involved no one can complain of those supplied by almost any branch of physics or mechanics and I believe the complete solutions of many of the problems that have yet only obtained the merest approximations as honorable as that of any of those

things that no one ever dreamed of. The hunt for something not known before in analytical combinations, and for things that might be if space had only a few more dimensions, is to my mind very similar to, and of about as much importance practically as, the hunt by the globe trotter for a place no foreigner has ever visited, simply for the honor of having been the first to be there. Even the text-books written by authors who profess to make them suitable for technical institutions contain very little rational explanation of how the subject is to be applied and leave many openings for the student to stumble into. They use too much space on what may be pretty, and to some probably interesting; but, for the present purpose, useless analytical ornamentation. What the engineer wants is a discussion of the fundamental principles of the subject with proofs of such theorems as are required built on perfectly sure foundations. When such proofs cannot well be given, let the theorem be clearly stated and the cases to which it is applicable be fully explained. There is nothing more unsatisfactory than to be presented with a *general* theorem and have it more or less fully demonstrated and then to be told that in this case and in that it will fail for particular reasons. It is even worse to have it stated, as is often done with reference to Taylor's theorem for example, that by an artifice these cases can also be brought within the range of the theorem without pointing out that even this artifice will not always be sufficient. There must be an intelligible way of stating the conditions under which such theorems are applicable which would enable an ordinarily intelligent man to decide at once whether it may be used or not. It is important to have a good sound exposition of the way to deal with problems involving multiple integrals and the order of integration or differentiation of these expressions together with a discussion, with practical illustrations, of the errors which may arise if they are not properly dealt with. The physical meaning of the different steps in the mathematical treatment of a subject should be made perfectly clear and all tendency to purely mechanical treatment avoided. One other point may perhaps be worth mentioning, that is, the great value of sound methods of obtaining approximately the values of the real root or roots of cubic and higher equations and the comparatively small value of the complete solution on which much time is apt to be spent in mathematical teaching. It may be objected perhaps that to cut down the subject to the treatment of the comparatively few

fundamental principles that are required in ordinary practical applications would be to drop the mental discipline which can be obtained from the study of abstract mathematics. I do not consider however that the ordinary college text books, as they now stand, are brilliant examples of close reasoning and I think that the arguments brought forward for the study of mathematics will apply just as well to the study of practical physics or mechanics.

Similarly, in the treatment of dynamics and the application of mathematics to physical problems, a discussion of the essential principles of the subject is much more important than the solution of a large number of problems especially adapted to give play to analytical ability. The illustrative examples should be as much as possible of such a character as to dispel any doubt in the mind of the student as to whether the subject he is studying can have any bearing on practical affairs. The examples should also be so stated as to give practice in the expression of physical relations in mathematical language.

In the scientific discussion of a subject there is nothing more important than perfect definiteness as to the meaning of terms and the consistent use of these terms throughout. There is, for instance, supposed to be some insuperable difficulty about the use of the word pound because engineers, and practical men generally, are in the habit of giving the same answer to questions as to quantity of material and as to heaviness of the material. Many English words have several meanings and little or no ambiguity results, because the context supplies the key to the meaning, but when things are to be expressed mathematically endless confusion is apt to result from a symbol having a double meaning. The question then is which of the several meanings is the more logical or the more convenient. In this particular case there can be no difficulty in deciding because only one is definite, the quantity of matter represented by a pound is the same always but the heaviness depends on where it is. Some explanation must therefore always accompany the word when it means heaviness to make it intelligible as for example a force equal to the weight of so many pounds at Washington. This explanation is very simply given by proper definition of units and the multiplication of the number representing the quantity of matter by the number representing the force of gravity on the unit quantity of matter at the place where the body is. That is to say pounds represent quantity of matter and heaviness is deduced by multiplying by the proper coëfficient.

It so happens that this coëfficient may for most engineering purposes be taken as a constant; and hence the discussion between the scientific men who wish to be truly consistent and scientific and a few others also, for the most part, professional scientific men who pose as the champions of the practical man and wish to save him from an imaginary difficulty. Let us make our dynamics as simple and consistent as possible and teach, both in books and in oral discussion, so that an average brain can comprehend what we are driving at and the practical man will never trouble us with such difficulties. It is not my intention here to discuss the question of the best system of units but I wish to repudiate the idea that the so-called practical men are so much inferior intellectually to the men who write our average text-books on mathematics and dynamics, that they are incapable of understanding so simple a matter as the difference between inertia or inertia reaction and the accidental heaviness of a body.

As a knowledge of applied mathematics became more general and as experience was gained in the methods of applying calculation to mechanical problems, simple rules for the solution of different classes of practical problems have been contrived and they are rapidly increasing in number. Immediately it became apparent that mathematical computation might, under certain conditions, be substituted for experimental trials, engineers were not slow to make use of the fact or to acquire the requisite knowledge of mathematical rules. We cannot blame them, however, for considering that the pupils of a few enthusiasts in the application of mathematics, who had no doubt been taught a good deal of mathematics and dynamics and had solved a number of possible but perhaps not very probable mechanical problems but who had had no experience, knew nothing of engineering. They naturally preferred to employ a man who had served a regular apprenticeship and had paid some engineer and not a college professor for his tuition.

There are at least three distinct schemes for technical instruction before the public having different objects but which are seldom properly separated from each other in the discussion of the general subject. These three schemes are represented by Manual Training Schools, Apprenticeship or Trades Schools, and Technical Colleges. With the first two of these mechanical science as above defined has only a somewhat indirect connection; with the third the connection is close and important.

The institution of manual training schools and the introduction

of manual training into the primary and secondary schools is receiving much attention in several countries. The object is to give the opportunity to the scholars of learning how to use their hands to some advantage whether it be to saw or plane, to chip or file, to carve or to paint. There can be no doubt that to many boys and girls some of these occupations will give very pleasing sources of recreation and study. If combined with this, some elementary instruction be given in such subjects as general building construction, including plumbing, gasfitting, wiring for electric lights, and so forth, so as to give every man and woman a sensible notion of what is in their house and how to repair it in an emergency much valuable information may be imparted. The object of this kind of instruction is not to make skilled workmen but simply to impart some information as to how tools are handled and to give the opportunity to train the hand and eye as well as the mind. To many of us who have to take up these scholars after they have left the secondary schools and attempt to carry the education forward in specific subjects, it may appear doubtful if the time can be spared after that required for the ordinary and very important subjects of reading and spelling, composition, arithmetic, elementary science and so forth is provided for. No doubt there are a few subjects taught in most schools the future use of which is very doubtful but there is also no doubt but that the other subjects could absorb much more time with advantage. It is not clear to my mind that manual training is of equal importance or can be imparted with as much advantage in the primary or secondary schools as the more commonly recognized subjects. It is certain that few of these schools give anything like a complete elementary education and still fewer provide adequate preparation for the colleges and universities.

Trades schools, or apprenticeship schools as they are sometimes called, aim to provide the tradesmen required for the construction of engineering works. The engineer, in some capacity or other, provides work for almost all classes of workmen and he is interested in the preparation of such men for the practice of their trades. In this age also the right of every member of the rank and file to the position corresponding to the officer or general in military affairs is recognized and encouraged with the view of bringing the best men to the front. One of the best means of reaching this end is to place the workman as high as possible in the educational scale and provide him with the means to easily reach higher. While all

this is true, and while considerable success seems to have attended several of these schools in some countries, it seems after all a poor and very expensive substitute for the old method of learning a trade by apprenticeship. It is asserted that the whole aspect of nearly all the trades has become so changed that the old method is an impossibility. That the manufactures are nearly all produced largely by the aid of machinery, that the manufacturer is not and never was a handicraftsman as of old, but is a capitalist whose sole object is to increase output and reap profits on his investments. Some part of this is true and it is assumed that because the employer of labor is a capitalist he has no interest in the instruction of those who do his work. It is said also that in the good old days the master himself gave the requisite instruction to his apprentices and therefore it is assumed they were better instructed. That the employer of labor has no interest in the instruction of his employés is not true, and that it is necessary for the master to be a workman in order that his apprentices may learn their trade, is absurd, and has never to any very great extent been the case in the manufacturing centres in this generation.

The extensive use of machinery in large shops has no doubt changed largely the kind of workmen required in these establishments. It is claimed by some that machinery has largely taken the place of unskilled labor and therefore that the tendency is to increase the proportion of skilled to unskilled workmen. There would appear to be involved in this the idea that heavy work requires less manipulative skill than light work or that there is less skill required to shape a piece of work or to cut a screw thread by hand, than is required to fix a tool and look at a machine do it.

The large use, and in many cases the abuse, of machine methods with which we are familar nowadays do not increase the manipulative skill of the workmen, but make in many cases an opening for the employment, in the place of the skilled workman, of boys and girls and day laborers. It does not follow of course, that, because much of the work in these establishments can be done by unskilled labor plus machinery, it is not possible to learn to be a skilled workman there. The chief difficulty lies in the division of labor or specialist system now so common. As a consequence of this it is possible for a man, at least when work is abundant, to earn as good wages and to have as constant employment by learning to do one thing well as he would be able to do by learn-

ing the whole trade. The temptation to do this is that in a comparatively short time after entering the shop a youth is able to rank as an expert workman. The drawback of course is the smallness of the man's resources in the case of a depression of trade. The man who will be content to do this rather than acquire the ability to fill a position in different departments, or who can spend year after year in a shop without learning how his next neighbor does his work will not be changed by the institution of a trades school. It is a very different thing to give instructions to a man who wants to learn and to do the same thing to another man who has been forced to appear to learn.

The trades school aims at providing the means of educating artisans in the different branches of their trade and also in most cases provides for increased general education in science and art. How can this be effectively done for any one trade? Clearly it is necessary that work must be done on a moderately extensive scale and on ordinary business principles. Most of the schools have, I believe, advocated the production of quality rather than quantity of work. Manipulative skill is the thing aimed at and they have at the same time professed as the main object the production of foremen or overseers. A good foreman wants a great deal more than manipulative skill; he wants to know just how much to value a certain class of work against the time taken to do it, and he wants to have a wide experience in different kinds of work, in the quality of materials, in the management of workmen under ordinary business conditions and so forth. If he is to acquire that in the school the school must be an ordinary shop where work is done in the ordinary way. It should turn out work of a kind that will compete with the ordinary shops; and besides it should be conducted on business principles and be a paying, self-supporting concern. If there be a real difficulty in the production of skilled workmen, an institution of this kind ought to be possible and ought to come from, and be supported by, the manufacturers themselves. It appears to me however that something involving much less trouble and much more likely to succeed could easily be arranged for on the old lines of work. All that is necessary is for the manufacturers to encourage those who wish to learn the different branches to do so, and for the educationalist to see that the means of obtaining scientific training is at hand, say in the evening schools, for those who wish to study.

The branch of technical education which most directly concerns us here, is the university or technical college course. It is in the work done in these institutions that we may hope for data which will tend towards the advancement of mechanical science and the production of this data either is or ought to be one of the primary objects of all technical colleges. Most of these colleges and the technical departments of the universities have made more or less elaborate arrangements for workshop instruction, and in some cases this seems to have been considered of much more pressing importance than the laboratory part of the scientific instruction. Fortunately this is being changed and well-equipped laboratories are being provided in most of these institutions.

There can be no reasonable doubt but that young men, who propose to become engineers and who have had a fairly good primary and secondary school education, with or without manual training, will find the courses of instruction in these technical colleges a great assistance to them in their after career. It is also possible, I believe, so to manage the workshop part of the course that the student of mechanical engineering will learn a great deal as to how work is done in a machine shop; and the office and field work part in such a way that the student of railway or sanitary or other form of civil engineering will acquire a fair knowledge of how such work is done. They can become familiar with the requirements and the management of machinery and machine tools, and may by seeing work produced by expert workmen, and by assisting in its production get to know when a piece of work is well done, when it is roughed out and when it is finished. They may even learn a little of business management, but there is not yet any royal road to experience and college pupils never can be expected, when they leave the classroom, to take a place as full-fledged members of the engineering profession. Neither can these young men expect, unless they have had previous training, to hold their own in an ordinary office or machine shop alongside of men who have spent years in simply learning the routine of how to do such work, and whose chief effort has been directed toward the acquirement of expertness in execution because on that the amount or the constancy of his income largely depends. Expert workmen, or foremen, or managers, or draughtsmen, or even computers, are seldom made at college. It is almost needless to add that the average college graduate will not be content to attend to one small division of labor and

be himself a machine till some one contrives another in brass and iron to take his place. These colleges do not provide the proper food for ordinary workmen but aim to make a man who, with a little practical training and the necessary experience, will be fit for any position. It should be remembered by those who wish everybody to be alike and to receive the best of everything, that workmen are needed by the thousand, while directing foremen and managers are needed by the tens and ones;—in fact that high positions are few and average positions only moderately plentiful;—also that a brilliant gem will shine whether it be polished or not.

If we want to advance mechanical science and consequently engineering, let us keep clearly before us what each department taking part in the subject can best do and let the college instructor and the workshop instructor and the manufacturer or the practical engineer work together as parts of the same educational machine. Undoubtedly the college class can do much to assist the practical engineer in obtaining valuable recruits to the profession and in raising the standard of these recruits higher and higher. Particularly is this the case in the direction of knowledge of general principles or laws which have already been discovered and in the equipment of every man with a fair knowledge of mathematics and physics and other allied branches of science. In this way the apprentice can be turned to useful account from the beginning and he, from his training in how to observe, acquires experience rapidly when given the opportunity to do so. When a clear conception is obtained of how much data is necessary to enable a correct conclusion to be reached and how many and what kind of observations of a number of unknown or doubtful quantities are necessary to enable the requisite equations to be formed so that, by the solution of these, definite values can be given to each of the unknown quantities, the work becomes direct and the progress rapid. The principle of the equilibrium of forces has given, under certain conditions, direct methods of solving either by analytical or graphical methods very intricate problems as to the stress to which the different parts of a structure or machine may be subjected. The limiting conditions, necessary to enable such solutions to be obtained, have, however, caused great changes to be made in the form of the structures themselves which may in some cases, be of doubtful advantage. Hence the man who wants to fit his designs to easy calculations is apt to meet with opposition from the man who from

experience has been led to prefer a design which, in the present stage of the subject, is less easily tested by calculation. The methods which have already been developed have given a great impetus to the simplification of designs and have allowed the part played by each of the several pieces of a structure to be very much better understood. They have however tended to give to many structures a chain-like character in that their collapse in many cases may be brought about by the failure of a single piece, thus destroying the safety obtained from average strength and necessitating great care that every piece is equally sound and of good quality. Again the science of energy, its conservation and transformation, has made great progress and has done much to instruct in and to simplify the science of machines, their actual or calculated or possible efficiency and so forth.

Another branch of inquiry which was very early recognized as important is obtaining more and more attention, that is, the properties of the materials out of which structures and machines are made. The effect of impurities or changes in the composition of these materials or their adaptability to particular uses is an important inquiry. There is no subject, perhaps of more importance to the engineer and to the advance of engineering science than that of the best methods of obtaining information as to the physical properties of materials by tests. There has been a great deal of discussion in various scientific and engineering societies on this subject and yet there is a great deal to do and pretty nearly the whole subject to learn. Attempts have been made to lay down rules for uniformity of practice in the purely practical part of the subject, and some such rules may be of considerable use, but we should not lose sight of the fact that rigid rules laid down and once adopted are apt to prove bars instead of helps to progress in the scientific part. They are apt to diminish experimental inquiry and to make it difficult to change after knowledge has gone in advance of the rules. Manufacturers of materials quickly acquire facility in producing materials which will fulfil a standard set of tests and will continue to do so, when they could with equal ease produce better; and any demand for a different class of material is at once met by a demand for a higher price.

The question of how much can be learned from tests of small specimens and whether for satisfactory results, full-sized pieces are required is an important subject which will bear considerable more

investigation than it has yet received. It seems probable that careful comparison of results obtained with graduated sizes of the same material will lead to results which will enable moderate sized pieces to be used for nearly all ordinary testing. I must confess to having doubts as to the great advantage to be derived from very large test pieces except in special cases. We cannot both break the piece and use it and two large pieces are seldom exactly alike. Hence the question becomes one as to whether without actually spoiling the piece we can perform satisfactory tests upon it. Certainly it would be a good thing to subject all the actual pieces to a proof test so as to insure absence from flaws, and by proper arrangements for observing the elastic behavior of the piece this can be done without any danger of producing weak places. There is another problem I should like to see worked out to some extent, that is, the advantage or disadvantage of producing a small initial set in all pieces to be used in structures, a species of tempering in fact for the purpose of eliminating internal local stresses.

There is no doubt from the results of a great many observers that a piece of most kinds of manufactured material can be made to bear enormously more stress without set by giving it an initial set in the direction in which the working stresses are to be applied. To what is this due? Is it because the whole of the material is not in a condition to take its part of the load in the initial condition, or is it entirely molecular, and is the change permanent? Again, would it be well to first give the piece a permanent set and afterwards anneal it, and does annealing produce uniformity and freedom from internal stress? The changes of the dimensions of metals and particularly of alloys with time are, in this connection, of great interest. There is, for example, evidence that changes do occur with time in the dimension of some alloys in the fact that one of the old standards of length in the offices of the coast and geodetic survey has changed its length by a very sensible amount.

The cause of the crystalline structure so commonly observed in old railway axles and its connection or nonconnection with ultimate fracture has received considerable attention and has been the subject of much speculation, but very little advance has been made in real knowledge of the subject. One important point to be decided is this: can the crystalline structure be readily removed without remelting or spoiling the piece, and would it be safe or would it be possible by periodic treatment to render such pieces suffi-

ciently permanent to wear out? Another subject closely allied to this may be mentioned, namely, the relative effect of live and dead loads and the proper coëfficient to use for each. Are experiments on the actual breaking load under repeated or alternating stress of value as showing the safe working load? I believe more experiments are wanted on this subject with loads well within the elastic limit the repeated application of which is continued for a long time with view of determining whether the elastic limit is narrowed or whether there is, in fact, any real elastic limit for repeated loading. The evidences of elastic fatigue or the development of great molecular viscosity; the effect of rate of vibration, and the effect of rest, and the repetition of periods of work and periods of rest are all important subjects for extended investigation. The simultaneous change in the other physical properties might be added as also important, but perhaps in a sense somewhat outside our domain.

It has sometimes been suggested that resilience is the most important element in many structures, and hence in the parts, and there is a good deal to be said in favor of extending our knowledge of the resilience of materials. For most purposes elastic resilience is most important because although a substance capable of considerable change of dimensions without fracture has a high total resilience such a change is seldom allowable in a structure which is to be permanent.

It is not even allowable in such structures as crane chains but is in such cases a source of great danger. When a chain has been subjected to much rough usage and has been found to bear the weight and the jerks of certain loads, this usage and rate of loading are continued. If then the chain has been saving itself by stretching it will ultimately become unsafe and will give way probably with a less load than many which it has formerly been found able to bear. The result is said to be an accident, whereas it might have been readily predicted if a little careful observation had been made. Changes of dimensions and shape of all structures with time should be carefully observed, because if these be great they indicate weakness and danger.

A fruitful source of inquiry would be the systematic observation of the effect of the working load on such structures as railway bridges in order to determine the change of figure and the vibration produced in the structure. The relative effects of loads of varying density and length placed as a dead load and made to run

on at different speeds would be of great interest as likely to show whether any particular rate of loading would be likely to develop dangerous vibrations. The relative efficiency and the stresses produced both in the structure and in the locomotive by improper balancing are also problems of interest and practical value.

In steam engineering there are still many problems on which further investigations might with advantage be spent: for example, the initial condensation and subsequent reëvaporation of the steam in the engine cylinder, particularly in condensing engines. The comparison of the efficiency of high expansion, with, say, a moderate amount of superheating, in one cylinder *versus* multiple cylinder expansion, relative effects of different methods of preventing condensation in the cylinder; methods of observing the actual condition of the steam at different parts of the stroke at different points of the cross section of the cylinder. The subject of reliable methods of testing quality of steam or the amount of water it contains has lately received considerable attention which so far has only served to show how very unsatisfactory the ordinary methods are. The whole subject of steam colorimetry, including both the method of taking the specimen of the steam and the method of determining its wetness, is in fact open for experiment and improvement in experimental methods. Profitable work may still be done on the subject of the best construction of boiler furnaces with the contingent ones of rate of firing, contact *versus* radiation in heating, rate at which heat may be taken from the gases consistent with approximately perfect combustion, smoke consumption, etc. The question of the consumption of fuel in furnaces under boilers producing steam *versus* the direct combustion in the cylinder itself, such as is the case for instance in the gas engine, is one of the very greatest importance and the development of hot gas engines from this point of view is likely to lead to a revolution in the methods of using fuel for the production of power. The indication of engines for the power developed is one which many may consider as practically perfect. As a matter of fact it has not progressed much since the days of Watt. A diagram is drawn on a very small scale of the operation of the steam in the cylinder during one stroke. The back pressure part belongs really to the diagram for the other end, and the curves are subject to very complex errors due to the indicator itself. This diagram is then used as an average from which the total power can be cal-

culated. For steady working engines in which the number of strokes per minute is not large this method can, with proper care, be made to give approximate results as to power and a fair indication of the action of the steam. In engines in which the variations of pressure are rapid and the number of revolutions per minute great the inertia of the parts of the indicator becomes important and it is difficult to obtain reliable results. It is certainly possible to improve on this and some good work in the right direction has recently been done. That work embraces two points of importance, namely, the integration of the work done over a considerable number of strokes and the scopic observation of the action of the engine by means of a beam of light reflected from a mirror which is made to show the motion of the indicator. I think this latter idea, which has been recently worked out by Professor Perry, may prove of great value, not only as an investigating but as a teaching instrument for showing variations in the diagram with varying conditions of loading, valve setting and so forth.

In machinery generally the question of friction and lubrication, which was very fully brought before this section last year, brings in a whole host of problems as to the best kind of lubricant under different conditions of pressure and rate of running, the best mode of applying the lubricant, the effect of the state of the surface, and so forth; the best combination of materials for bearings as influenced by their durability, coëfficient of friction, conductivity for heat and a variety of other considerations. Again, the determination of the power absorbed in the running of idle as compared with loaded engines and machine tools, with the probable advantage or disadvantage of division of power or of the electrical distribution of power, is one on which reliable data are valuable.

The applications of electricity which is one of the most important branches of mechanical engineering bring before the investigator a large number of new problems in an entirely new field of inquiry. The study of the laws of electricity and magnetism and the electrical and magnetic properties of materials has now as direct a practical application as that of elasticity above referred to. The design and construction of electrical machinery and the application of electricity as a means of distributing energy have furnished problems for a large number of enthusiastic workers and will probably continue to do so for many years. Among the most interesting and important are the effect of magnetic permeability

and ohmic resistance on the effective section of a conductor for conveying alternating currents, and the effect of magnetic permeability and its variable character on the passage of varying currents through circuits surrounding magnetic material such as iron.

It is on the careful and quantitative investigation of problems of the kind here mentioned that the progress of knowledge of mechanical science depends. I hope the workers will continue to be plentiful and the harvest good.

PAPERS READ.

ON THE CRUSHING OF SHORT PRISMS OF HOMOGENEOUS MATERIAL. By CHARLES L. BOUTON, 2909 Park Ave., St. Louis, Mo.

[ABSTRACT.]

THE object of this paper is to discuss the manner in which prisms of homogeneous materials fail in compression. Early in this century Coulomb published a theory according to which the failure would take place by shearing along planes inclined at 45° to the base. Navier modified this theory by introducing friction, and concluded that failure should take place along planes inclined at $45° + \frac{\phi}{2}$ to the base, where ϕ is the angle of repose for the material. It is urged against both of these theories that they give a relation between shearing strength and crushing strength, which is far from true. The writer has somewhat modified Navier's theory by introducing a resistance at right angles to the applied force, due to friction on the ends of the prism. The consideration of this resistance leads to the following equations:

Let p = crushing strength per unit area.

p_h = stress per unit area at right angles to this.

S = shearing strength.

ϕ = angle of repose.

θ = inclination of shearing plane to base.

Then

$$\theta \; 45° + \frac{\phi}{2} \tag{1}$$

and

$$p = 2 \, S \tan \theta + p_h \tan^2 \theta \tag{2}$$

From my experiments I have obtained the following results:

Thirty tests on one kind of cast iron gave $\theta = 55°.0$ and $45° + \frac{\phi}{2} = 55°.3$. From twenty-four tests on another iron $\theta = 54°.8$, $45° + \frac{\phi}{2} = 53°.4$.

In all these tests the angle seemed to be independent of the height, which varied from one to three diameters.

Three square prisms of limestone gave $\theta = 62°.2$, $45° + \frac{\phi}{2} = 61°.7$.

Three square prisms of paving asphalt gave $\theta = 59°.7$, $45° + \frac{\phi}{2} = 58°.7$.

Three square prisms of cast iron gave $\theta = 53°.4$, $45° + \frac{\phi}{2} = 52°.2$.

These results are very satisfactory and seem to do much towards establishing this part of the theory.

For cylinders of cast iron of any one diameter it was found that the strength could be represented by

$$p = a + b\left(\frac{D}{h}\right) \qquad (3)$$

where D and h are the diameter and height respectively of the prism, and a and b are empirical constants.

Now if this is the same as equation (2) we should have

$$a = 2\,S\,tan\,\theta$$

By getting a from the equation which represents the strength of the iron, and finding the shearing strength from experiment the following results were obtained:

First iron

$$\left.\begin{aligned} 2\,S\,tan\,\theta &= 80{,}000 \\ a &= 80{,}200 \end{aligned}\right\} \text{for } D = 0.''94$$

$$\left.\begin{aligned} 2\,S\,tan\,\theta &= 73{,}200 \\ a &= 77{,}400 \end{aligned}\right\} \text{for } D = 0.''67$$

Second iron

$$\left.\begin{aligned} 2\,S\,tan\,\theta &= 74{,}900 \\ a &= 75{,}800 \end{aligned}\right\} \text{for } D = 0.''89$$

From the agreement shown above between experiment and the theory, we may conclude that Navier's theory as above modified is practically correct for the materials tested.

THE GOVERNMENT TIMBER TESTS. By Dr. B. E. FERNOW, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE author said there had been inaugurated in the forestry division of the Department of Agriculture a comprehensive series of tests and examinations of American timbers, the ultimate object of which is the solution of a biological problem, namely, to establish the relation of technical and physical qualities to each other and to conditions of growth. In the pursuit of this investigation, naturally, many questions of immediate practical value in the use of wood for engineering purposes will be solved.

The novelty in this enterprise lies mainly in its comprehensiveness and scope. A very large number of tests alone on material of known origin and condition and an exhaustive examination of the same will permit generalization and the recognition of laws of interrelation.

The work requires the organization of four distinct departments. First, the selection of test material from as many essentially different climatic and soil conditions as the species may occupy, five fully matured and two young trees being carefully selected on each site and cut up for test material; secondly, the examination of the structure and physical condition of the test material requiring the minutest detail; thirdly, the usual testing with special care, and, lastly, the compilation and comparative discus-

sion of the results of the tests in connection with the physical examination and the known conditions of growth.

Besides more reliable data than hitherto attainable of the qualities of our principal timbers, there is to be gained from this investigation a knowledge of conditions under which desirable qualities can be produced by the forest grower.

THE UNITED STATES TESTS OF AMERICAN WOODS, MADE AT THE WASHINGTON UNIVERSITY TESTING LABORATORY. By Prof. JOHN B. JOHNSON, Director of Testing Laboratory, Washington University, St. Louis, Mo.

[ABSTRACT.]

THE timber is received in the log, these being twelve to eighteen feet in length. They are sawed on stenciled lines, and the sticks staked under shelter. There are two standard sizes of sticks, small specimens, four inches square, and larger sticks, from 6 x 12 to 8 x 16 inches. Two small sticks and one large one are obtained from each log. These are tested both green and dry, for cross-bending tension, compression endwise, compression sidewise, and for shearing. The specific gravity and the percentage of moisture are also obtained. All pertinent facts, as size and conditions of growth, geographical location, position of specimen in tree, character of fracture, etc., etc., are made matters of permanent record From the cross-bending test not only the breaking strength but the modulus of elasticity and the relative elastic cross-breaking resilience are obtained.

ON EXPANSION STEAM CALORIMETERS. By Prof. THOMAS GRAY, Rose Polytechnic Institute, Terre Haute, Ind.

[ABSTRACT.]

THIS paper refers to the construction of calorimeters, the indications of which depend on the change of temperature produced by the combined action of expansion and the absorption of water by the expanded steam. It is pointed out that considerable error is apt to arise due to the fact that all the water is not absorbed by the steam even when it issues in a superheated condition and points out the changes of construction required so as to avoid this error.

ON THE POWER ABSORBED IN THE CUTTING OF METALS. By Prof. THOMAS GRAY, Rose Polytechnic Institute, Terre Haute, Ind.

[ABSTRACT.]

THIS is a continuation of the paper contributed at the Indianapolis meeting on the same subject. The results of a somewhat more extended set of tests are given and some changes in the method of operation are described.

TESTS OF ELECTRIC RAILWAY PLANT. By Prof. THOMAS GRAY, Rose Polytechnic Institute, Terre Haute, Ind.

[ABSTRACT.]

IN this paper the apparatus and methods adopted in some recent tests of the Electric Railway Plant at Terre Haute, Ind., are described; and the total horse power absorbed, the extreme variation of power and the power per car is given. In the tests an automatic recording dynamometer was used for indicating the power absorbed, by the dynamo and electrolytic cells placed in the main and car circuits were used for obtaining the total electric energy absorbed.

MAXIMUM ERROR DUE TO NEGLECTING THE RADIATION CORRECTION OF A BARRUS UNIVERSAL CALORIMETER. By Prof. D. S. JACOBUS, Hoboken, N. J.

[ABSTRACT.]

THE results are presented of experiments made with a calorimeter, supplied with steam which was made exactly dry, by superheating with gas jets, when it entered the instrument, so that the losses of heat by radiation of both the separator and the heat gauge portions of the calorimeter were determined with precision.

RELATIVE VALUE OF CARBONIC ACID AS THE WORKING FLUID IN REFRIGERATING MACHINES. By Prof. D. S. JACOBUS, Hoboken, N. J.

[ABSTRACT.]

THE refrigerating effect of one cubic foot of carbonic acid is computed from reliable experimental data, and the result compared with parallel figures for anhydrous ammonia for the production of temperatures of 5° and minus 22° Fahr.

RELATIVE COMMERCIAL ECONOMY OF COMPOUND AND TRIPLE EXPANSION ENGINES. By Prof. J. E. DENTON, Hoboken, N. J.

[ABSTRACT.]

THE water and coal consumption and cost of plant per horse-power are given for the best modern types of the two kinds of engine, and the superior economy of the triple style, shown to be equal to 2 3 per cent of the cost of fuel for the compound type, for ten-hour service.

NOTE ON THE EFFICIENCY OF THE SCREW PROPELLER. By Prof. J. E. DENTON, Hoboken, N. J.

[ABSTRACT.]

ATTENTION is drawn to the fact that the generalization or efficiency of screws given by Froude, and found in standard modern manuals, is subject to considerable modification in the light of modern data. Also that the measured performances of screws vary so widely, that it is not possible to draw conclusions at all general in their application.

ON A METHOD OF HOLDING SAMPLES OF WOOD AND BRICK FOR DETERMINATION OF TENSILE STRENGTH. By Prof. J. E. DENTON, Hoboken, N. J.

[ABSTRACT.]

AN account of the success of attempts to test samples of brick and wood, without reducing the section of the portion between the holding points.

ECONOMY PRODUCED BY THE USE OF WATER INJECTED AS FINE SPRAY INTO AIR COMPRESSORS. By F. F. GAUSE and J. C. POST. Presented by Prof. J. E. DENTON, Hoboken, N. J.

[ABSTRACT.]

THE results are presented of experiments, with an 8 × 12 single acting air compressor, made to determine the relative economy produced by cooling the air during compression with a water jacket, a solid half-inch jet, and fine spray, using the same quantity of water per unit of time in each case.

ON THE OPPORTUNITY FOR MECHANICAL RESEARCH AT THE WORLD'S FAIR. By WILLIAM KENT, 125 Times Building., New York, N. Y.

[ABSTRACT.]

AT the Centennial Exhibition in 1876, a series of boiler tests were made which have proved of great service to the engineering profession in establishing the limits of efficiency to be expected in boilers, and the conditions upon which maximum efficiency depends. International exhibitions offer exceptionally favorable conditions for the testing of mechanical appliances, for the reason that at such exhibitions there are apt to be grouped together on a large scale several varieties of the same class of appliance, each representing the best ideas of its builder. It is possible at such exhibitions to carry on an extensive series of tests under practically uniform conditions, which cannot be obtained when the apparatus is located at widely separated points and tested by different experts.

The writer has brought to the attention of the authorities of the Chicago Exhibition the advisability of making tests of fuels, furnaces, engines, pumps, methods of transmitting power, such as gearing, belting, shafting, rope driving, pneumatic, hydraulic and electric transmission, etc., machine tools and other mechanical apparatus. The council of the American Society of Mechanical Engineers has at the request of the mechanical department of the exhibition appointed a committee to recommend a scheme for such tests as have been proposed. This note is presented before section D for the purpose of inviting discussion as to the plan and scope of such tests and the means by which they may be made to furnish results of permanent value to mechanical science.

ON THE EFFICIENCY OF THE STEAM JACKETS OF THE PAWTUCKET PUMPING ENGINE. By WILLIAM KENT, 125 Times Building, New York, N. Y.

[ABSTRACT.]

THE engine is a cross compound. Diameter of steam cylinders 15″ and 30″, water cylinders 10.52″, stroke 30″, clearances, high 4%, low, 3.7%, diameter of rods 2¾.″ Especial pains were taken to secure accuracy in the tests, and the results confirm those found by Professor Denton in the same engine a year earlier. The water consumption per horse power per hour when the cylinder jackets and reheater were in use, was in three tests, 13.687, 14.041 and 13.952 lbs. When the jackets and reheater were not in use the figure was 14.256 lbs. The difference between the best result with the jacket and the one result without the jacket was only 3.99 %. The results are about as high as have ever been obtained in a two-cylinder compound engine.

[This paper will be revised and presented to the Amer. Society Mechanical Engineers at the November meeting.]

THE INFANCY OF THE MECHANIC ART. By J. ELFRETH WATKINS, C.E., Curator of the Section of Transportation and Engineering in the U. S. National Museum, Washington, D. C.

[ABSTRACT.]

THE mechanical art had its origin in prehistoric times. The author traces its history from the earliest Egyptian and Assyrian monuments and from the earliest writings, and shows that many great inventions of modern times have been foreshadowed and remained dormant for centuries, awaiting the time to arrive when the necessity for utilizing them arose.

ON EXPERIMENTAL RESULTS OBTAINED WITH A NEW FORM OF DIRECT ACTION PROPELLER. By Prof. DAVID P. TODD, Amherst, Mass.

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ADDRESS

BY

PROFESSOR JOHN J. STEVENSON,

VICE PRESIDENT, SECTION E.

THE CHEMUNG AND CATSKILL (UPPER DEVONIAN) ON THE EASTERN SIDE OF THE APPALACHIAN BASIN.

I.

I HAVE chosen as a topic: The Chemung and Catskill on the eastern side of the Appalachian Basin, indicating by this term the area between the Blue Ridge region at the east and the line of the Cincinnati uplift at the west. It embraced as a water-area during the later Devonian much of New York, Pennsylvania, Ohio, Virginia, West Virginia and eastern Kentucky. There is reason for the belief that the southern outlet through eastern Tennessee was closed during this time, so that communication with the ocean was at the west.

The Upper Devonian on the eastern side of this area has always attracted its full share of attention. Palæontologically it has intimate relations with the Lower Devonian and in some respects close relations with the Carboniferous, so that its place in the column remains even now, for some, an open question. The equivalence of Upper Devonian within the Appalachian Basin to that beyond the line of the Cincinnati uplift is still a sufficiently perplexing matter; while the origin and grouping of the beds within the Basin itself are far from being finally settled.

The earliest positive reference to the Old Red Sandstone is that by Amos Eaton,[1] who in 1821 regarded the red sandstone of the

[1] Memoirs of the Board of Agriculture of the State of N. Y., Vol. II, Albany, 1823, p. 6. The letter to Mr. Van Rensselaer is dated Dec. 17, 1821. A similar reference was made in A Geological and Agricultural Survey of the District Adjoining the Erie Canal. Albany, 1824, p. 92.

Catskill mountains as typically the same with the Old Red Sandstone of Werner and as distinctly different from the Red Sandstone of the Connecticut valley; at the same time recognizing its relations with the Carboniferous and placing it in the transition series.

Marcou[1] states that Richard C. Taylor published a paper in 1831, discussing the relations of the Old Red Sandstone to the Carboniferous; the same author in a later paper[2] exhibits clearly the place of the Red Sandstone in central Pennsylvania and its relation to the overlying Carboniferous. He appears to include it in the Secondary with the coals west of the Alleghanies, thus separating it from the graywackes below.

The first systematic classification of American rocks older than Carboniferous was presented in 1836 by H. D. Rogers,[3] who placed in two groups the beds between the Fossiliferous Sandstone (or Oriskany, as we now know it) and the Lower Carboniferous Sandstone (Vespertine or Pocono of later classification). These groups, Nos. VIII and IX of his column, were distinguished from the Carboniferous, which Rogers divided into four groups, afterwards numbered X, XI, XII and XIII. The same classification, with rather more of detail, was repeated in the second Pennsylvania report,[4] as well as in the Second Report of W. B. Rogers[5] on the survey of Virginia.

No distinct effort to subdivide the upper portion of the Devonian column of New York was made prior to preparation of the Third Report of the Geological Survey. In that report,[6] Mr. Conrad defines the "Old Redstone Group (Murchison)" as embracing

9. Olive sandstone.—Old red sandstone?
8. { Dark colored shales / Black slate

thus carrying it down to the base of the present Hamilton. In the same report, James Hall[7] introduced the term "Chemung" for gray beds in Chemung county, overlying those of his Ithaca group.

[1]Geology of North America, Zurich, 1858, p. 114. This paper by Taylor I have not seen.

[2]Transactions of the Geological Society of Pennsylvania. Phila., 1835, Vol. I, p. 177.

[3]First Annual Report of State Geologist. Harrisburg, 1836, pp. 12 to 15.

[4]Second Annual Report on the Geological Exploration of the State of Pennsylvania. By H. D. Rogers, Harrisburg, 1838.

[5]Second Report of Progress of the Geological Survey of Virginia for the year 1837. W. B. Rogers; 1838 pp. 75–80.

[6]Assembly Document, No. 275. Albany, 1839, p. 72.

[7]*Loc. cit.*, p. 322.

The fourth report[1] contains Vanuxem's description of the series in his district, giving a complete grouping of the higher rocks and placing the Montrose or Oneonta Sandstone at the top of the column. The same report contains the general classification by Professor Hall,[2] in which the terms Old Red Sandstone, Chemung Group, Portage Group occur in the order given. One year later Mather used the term "Catskill Mountain Series"[3] to designate all the rocks of the Catskill mountains from the Lower Carboniferous Sandstone (Pocono) of Rogers down to the base of the Marcellus Shale, thus making it equal to Formations VIII, IX and X of the Pennsylvania column. The term "Catskill Group" appears for the first time in Vanuxem's[4] final report, where it is used to designate the rocks at the top of the Devonian, which are regarded as fully equalling in importance the underlying Chemung and Hamilton, forming his Erie Division; so that the Erie and Catskill are equivalent to the VIII and IX of Rogers. No line of demarcation between Erie and Catskill was determined.

Hall's final report[5] appeared one year later and contained the grouping which has remained unchanged: Old Red Sandstone or Catskill, Chemung Group, Portage Group.

Fifteen years later appeared the final report[6] on the Geology of Pennsylvania, in which Chemung and Portage are called Vergent, and the Catskill is the Ponent of the palæozoic column. This report took shape long after the original corps of observers had been scattered and the field-note books were not worked up in all cases by those who had made them; so that the statements are sometimes obscure and local details are too often perplexing to readers not familiar with the ground. Little additional systematic information became available after the publication of Rogers' final report until the results obtained by the second geological survey of Pennsylvania became known.

The studies by assistants on the second Pennsylvania survey were very much in detail, owing largely to the immense economic importance attaching to the upper portion of the Devonian column. But this detailed study, though leading to close concord in record

[1] Assembly Document, No. 50, 1840, p. 381.
[2] *Loc. cit.*, pp. 452–453.
[3] Assembly Document, No. 150, 1841, pp 77–82.
[4] Geology of New York, Part III, Albany, 1842, p. 12.
[5] Geology of New York, Part IV, Albany, 1843, pp. 18–19.
[6] Geology of Pennsylvania. H. D. Rogers, Philadelphia, 1858.

of stratigraphical work, has led to wide difference of opinion in respect to lines of separation between the groups. As the area of Pennsylvania is large, great variations exist in physical characters of rocks and in vertical distribution of fossils, so that difference of opinion arose to a greater or less degree respecting the limitations of every group; but the difference is especially noteworthy in the case of Catskill and Chemung, for one observer carries the upper boundary line of Chemung almost 2000 feet higher up in the column than is done by another. One observer coming from the northeast along the easterly outcrop of the Devonian finds good reason to mark Catskill as beginning with the first appearance of Red Shales, while another coming from the west and south thinks that Chemung should close only with the final disappearance of the marine fauna. When these observers joined their work, their sections were in practical agreement, but were labeled very differently.

The uncertainty respecting the relations of Chemung and Catskill is due in no small degree to the fact that the earlier studies of those groups were made in New York and adjacent portions of Pennsylvania, without much knowledge of the conditions elsewhere. Had the study been begun at the south in Virginia, then carried northward along the easterly outcrop through Virginia, Maryland and Pennsylvania into New York; then begun again in western New York or Pennsylvania and carried eastward to the outcrop, many difficulties, now apparently so formidable, would have been unknown and the problem of relations, seemingly so perplexing, might have been easy of solution. At this time, however, the study can be prosecuted to better advantage than was possible even ten years ago, for the oil-borings of western Pennsylvania enable one to trace the beds through that region also, where in localities they are more than 2000 feet below the surface. Let us follow, then, the courses indicated, depending on the work of I. C. White, J. H. Carll and C. A. Ashburner in Pennsylvania, that of J. J. Stevenson in Virginia and Pennsylvania, with references to the work of James Hall and H. S. Williams in New York.

II.

In the southwestern portion of Virginia, near the Tennessee line, the Devonian is represented only by Black Shale,[1] belonging at

[1] Stevenson: Proc. Amer. Phil. Soc., Vol. XIX, pp. 223, 233, 243.

the base of the Hamilton; but within a few miles the Hamilton shows a greatly increased thickness,[1] while, between it and the Lower Carboniferous, there are 350 feet of rock carrying Chemung fossils to within fifty feet of the top. The fossils are most abundant in a red or bluish rock with conchoidal fracture, which is the same in all respects physically with some non-fossiliferous beds higher up in the section. Within sixty miles along the strike, this 350 feet has developed into a great series with well marked horizons in the lower part,[2] while the upper part has become flaggy with not a few massive beds. The succession now is, the thicknesses being estimated:

1.	Not fully exposed, containing much red sandstone,	700 ft.
2.	*Conglomerate*,	40 "
3.	Shales and sandstone,	1000 "
5.	Shales and flags,	1500 "
4.	*Conglomerate*,	30 "

But the No. 1 of the section contains gray beds in the lower portion which in some localities have yielded Chemung mollusks at not less than 300 feet above the conglomerate, while on New river, Va., where the thickness is somewhat greater, the Chemung forms were seen at about 500 feet above the conglomerate. But the reddish beds which prevail toward the top seem to be non-fossiliferous. The tint of these beds becomes more and more pronounced toward the northeast, until in Catawba mountain, somewhat more than twenty miles southwest of James river, they have the dismal red and greenish color so characteristic of the series along the Potomac. And yet, in McAfee's gap, only eight miles northward, *Spirifera disjuncta* and some other forms of Chemung type occur very near the top of the series, within a few feet of the Vespertine (Pocono) sandstone.

The other parts of the section can be observed at many places; the Upper Conglomerate contains flat pebbles, which frequently show the longer axis vertical to the plane of bedding; No. 3 contains concretionary sandstones passing downward into shales, with brown blue and red to deep red flags and flaggy sandstones. Chemung mollusks are especially abundant near the top. The lowest division consists of flags and shales, olive, gray, yellow, blue and drab, with but few fossils.

[1] Stevenson: Proc. Amer. Phil. Soc., Vol. XXII, p. 136.
[2] Stevenson: Amer. Phil. Soc. Proc., Vol. XXIV, p. 81 seq.

This is the section to James river, somewhat more than 150 miles from the Tennessee line. Details of measured sections made in recent years between the James and Potomac rivers, a distance of not far from 200 miles, have not been published; but we need not wait for detailed measurements in this interval. Observations by the writer and by others at many localities have proved the section persistent; and the same succession is shown along the Baltimore and Ohio railroad as it follows the Potomac river. Of course there are variations in structure; Mr. N. H. Darton tells me that the conglomerates are wanting in the section near Staunton, Virginia, but this is merely local; they are present elsewhere. Farther north, the upper beds or Catskill have an increased proportion of shale, often blood-red, and the sandstones show a more marked conchoidal fracture, while the whole section has a greatly increased thickness.

The Pennsylvania line is reached but a few miles north from the Potomac along the outcrop. Crossing that line, one enters Fulton county, where the succession is:[1]

1.	Catskill:	Shales,	1600 ft.	
		Sandstone and shale,	2100 "	3700 ft.
2.	Chemung:	Shales,	1000 "	
		Upper Conglomerate,	10 "	
		Shales and sandstone,	950 "	
		Lower Conglomerate,	10 "	
		Shales and flags,	1850 "	3820 ft.

The close resemblance to the Virginia section is apparent at once, the most notable change being simply the great increase in thickness of the upper portion. The upper Catskill consists for the most part of soft deep red shales with occasional sandstones; but the lower Catskill is made up of brownish or greenish to red cross-bedded, almost laminated sandstone, often looking as though it were worm eaten. Sometimes a large fragment remains on a hill top, resembling much a pile of thin boards. Occasionally more massive sandstone prevails, as along the Juniata river in central Bedford county of Pennsylvania, where no tendency to lamination was seen. The Catskill appears to be wholly non-fossiliferous along the eastern outcrop from central Virginia into New York.

[1]Geology of Bedford and Fulton counties. J. J. Stevenson, Harrisburg, 1882, pp. 73, 75. 82. I have re-arranged the section somewhat, placing the line between Chemung and Catskill 200 feet higher than in the original.

The absolute limit between Catskill and Chemung is indeterminable, for the passage from one to the other is practically imperceptible at most localities; the line drawn at any locality, whether on stratigraphical or palæontological grounds, is almost certain to be unsatisfactory at any other. In Fulton county, however, a marked lithological change occurs at about 1000 feet above the Upper Chemung Conglomerate, for there the alternations of red and yellow shales cease and the flaggy, almost laminated red sandstones begin. The last horizon of Chemung mollusks was found at 200 feet lower, where, at approximately 800 feet above the conglomerate, the writer originally drew the line between the two groups.

The interval between the conglomerates is filled with yellow to red shales and gray, brown, blue or red sandstones; the red beds form an insignificant portion of the section, but such as are present are strikingly like Catskill, for the shales are often bright red and the sandstones cross-bedded or in thin flags. Many of the beds in this interval are richly fossiliferous and the important horizons of Chemung lamellibranchs are at but a little way below the Upper Conglomerate. The lowest beds of the Chemung are shales and flags; the shales overlying the flags are yellow, gray, olive, dark brown and reddish; while the flags, which doubtless represent the Portage of New York, are almost wholly olive, and, unlike the overlying shales, appear to be very sparingly fossiliferous.

Beyond Fulton county northward into New York, we must depend almost wholly upon the work of Prof. I. C. White, who has demonstrated the stratigraphical relations of the beds under consideration to those of the Catskill area of New York, and has told the story with such clearness that there is no opportunity for any one to cavil. His grouping of the rocks, however, differs from that already given; he prefers to include as Catskill all beds down to 100 feet below the Upper Conglomerate, which is the lowest horizon at which he found fish remains; he regards as transition the beds below that fish bed to the lowest red bed, 150 feet above the Lower Conglomerate, and applies to them the term Chemung-Catskill; while the remaining beds of the section are taken by him to represent the Chemung and Portage of New York. He identifies the Upper Chemung Conglomerate of Fulton county with his Lackawaxen Conglomerate of the New York border and he gives the name of Allegrippus to the Lower Conglomerate.

The succession in Huntingdon county,[1] Pennsylvania, is:

1. Catskill,		2500 ft.
2. Chemung:		
1. Haun's Bridge group,	1,000 ft.	
2. *Lackawaxen Conglomerate*,	20 "	
3. Sandstones and shales,	1,000 "	
4. *Allegrippus Conglomerate*,	5 "	
5. Shales and flags,	3,250 "	4,675 ft.

The Haun's Bridge group consists largely of greenish gray sandy shales and flags with some red beds, and holds from bottom to top Chemung mollusks, some of which are very abundant.

Professor White's measurements near Catawissa,[2] in Columbia county, Pennsylvania, about sixty miles further along the strike, show the section still persistent, the succession being:

1. Catskill,		3,230 ft.
2. Chemung:		
1. Shales and sandstones,	923 ft.	
2. *Lackawaxen Conglomerate*,	40 "	
3. Shales and sandstone,	1,180 "	
4. *Allegrippus Conglomerate*,	10 "	
5. Shales, sandstones and shaly beds,	2,300 "	4,453 ft.

The Catskill exhibits little change in structure and, as before, appears to have no fossils aside from obscure fish remains. No. 1 of the Chemung is the same with the Montrose shales of Susquehanna county as well as the Haun's Bridge group of Huntingdon county. It consists, as it does further south, of variegated shales and sandstones, green and red predominating, and in the lower half has many beds carrying Chemung mollusks. I have drawn the line between Chemung and Catskill somewhat arbitrarily, where sandstone ceases to predominate, for there is no noteworthy physical change in character of the rocks anywhere above the Lackawaxen Conglomerate. That conglomerate is now irregular in

[1] I. C. White in Geology of Huntingdon County, Harrisburg, 1885, pp. 92–104. As given here, Nos. 1, 2 and 100 feet of No. 3 of the Chemung belong to Professor White's Catskill; the rest of No. 3, except 150 feet at the base, forms the Chemung-Catskill of the same author. All sections along this outcrop, quoted from Professor White, have been re-arranged in this way.

[2] The Geology of the Susquehanna River Region. I. C. White, Harrisburg, 1883, p. 57.

structure, sometimes not conglomerate, but still containing fish-bones as it does further south. The fragments of bones are larger and in better preservation than at the more southern localities.

The interval between the conglomerates contains some red beds, but as usual they form only a small part of the section, little more than ten per cent of the whole. A bed containing fragments belonging, apparently, to *Holoptychius*, associated with *Pleurotomaria* sp. and *Lingula spatulata* was observed at 150 feet below the *Lackawaxen Conglomerate*. Vegetable remains are not wanting, for *Archæopteris hybernica* is abundant above the fish bed. The Allegrippus Conglomerate is no longer a constant member of the series, though occasionally it is recognizable without difficulty as a massive sandstone, sometimes containing flat pebbles.

Thus far the section observed beyond the James river in Virginia has been persistent, the distance along the line of outcrop being not far from 500 miles. In Columbia county, however, the interval between the conglomerates is no longer richly fossiliferous, while fossils reach to but 516 feet above the Lackawaxen instead of to 1,000 feet as in Huntingdon county. The section is still sufficiently distinct at Hartville,[1] Luzerne county, Pa., about twenty miles farther along the strike; but thence northeastward, changes in structure become marked and are accompanied by a still more rapid disappearance of animal remains, so that within a few miles such remains seem to be almost wholly wanting in beds above the place of the Allegrippus Conglomerate.

Professor White's Pike county[2] section was measured along the Delaware river about fifty miles northeastward from the Catawissa locality and practically on the same line of outcrop. It illustrates the conditions in New York, for the Delaware river there cuts across the Catskill mountain region. The succession is:

Catskill:

Honesdale sandstone,	100 ft.
Montrose sandstone,	125 "

Chemung:

1. Montrose red shale,	100 ft.
2. Greenish gray sandstone,	30 "
3. *Lackawaxen Conglomerate*,	50 "
4. Greenish sandstone and shale,	300 "
5. Red shale,	50 "

[1] White, *loc. cit.*, p. 196.

[2] Geology of Pike and Munroe Counties. I. C. White, Harrisburg, 1882, pp. 73 and 94.

6. Delaware flags,	1,000 ft.	
7. New Milford shales and S. S.,	75 "	
8. Starucca beds,	600 "	
9. Sandstones and sandy shales,	1850 "	4,055 ft.

The highest beds of the Catskill, the Cherry Ridge shales, were not measured, but they add barely 150 feet, so that within little more than fifty miles the Catskill has lost almost 3,000 feet, while the Chemung is but 400 feet thinner. But it should be noted that the upper portion of the Chemung has lost much, while the lower portion has increased greatly. The Allegrippus Conglomerate belongs at the base of the Starucca beds but it is not present. Even the Lackawaxen is no longer persistent as a conglomerate and in some localities it is not even massive.

The most interesting feature of this section, characterizing also those obtained along fragmentary outcrops in Carbon and Monroe counties, say twenty-five miles southeast of that which has been followed, is the apparent absence of animal remains from the whole series above the lowest member of the section, there being no trace aside from what seems to be fragments of fish-bones in breccias of the Honesdale Sandstone.[1] *Archæopteris Jacksoni* is plentiful near the base of the Montrose shales.

We have followed this section along practically one line of outcrop for nearly 600 miles, from the northern boundary of Tennessee into southeastern New York. Its persistence, stratigraphically, is remarkable, since variations in structure are inconsiderable until within thirty miles of the New York border; but serious changes of some sort occurred during the long period of deposit, for, in the extreme south, even the representative of the Montrose Sandstone carries Chemung fossils, while in northeastern Pennsylvania and the immediately adjacent portions of New York, animal remains practically disappear above the horizon of the Allegrippus Conglomerate.

Let us now return to southern Pennsylvania and follow the section westward; but first let us re-label the Fulton county section, giving to its parts the geographical names applied in the counties between that and the Delaware river, so that the relations of the different parts of the section may be remembered. It becomes:

[1] Mr. C. S. Prosser informs me that he has discovered some lamellibranchs in the Delaware flags and some Spirifers in the Honesdale and stone, or possibly at the bases of the Cherry Ridge shale.

Catskill:

Cherry Ridge shales,	1,600 ft.
Montrose sandstone,	2,100 " 3,700 ft.

Chemung:

1. Montrose red shales,	1,000 ft.
2. Lackawaxen Conglomerate,	10 "
3. Shales and sandstones, including Delaware flags and Starucca beds,	950 "
4. Allegrippus Conglomerate,	10 "
5. Shales and flags, including Portage of New York,	1,850 " 3,820 ft.

The thickness of the section diminishes rapidly toward the west, so that on the western border of Bedford county, near the Maryland line, the Cherry Ridge shales have almost disappeared and the total thickness of Catskill, including doubtless some of the Montrose shale, is but 1,980 feet.[1] No outcrop is seen in the adjoining county of Somerset until the western edge has been reached, where, under the great anticlinal of Laurel Hill, the Youghiogheny river has cut down to the Delaware flags. There the Montrose sandstone is present, but only a few feet thick; while at not more than three miles further west, on the other side of the anticlinal, the Catskill has disappeared and the Vespertine (Pocono) rests directly on the Montrose shale.

The Chemung shows a similar decrease in the same direction; for, on the railroad section in western Bedford, the whole interval of Chemung and Hamilton is represented by a concealed space of 2,630 feet, giving to the Chemung a thickness of somewhat more than 1,800 feet. The exposures under Laurel Hill in the Youghiogheny and Conemaugh gaps suggest a continuance of the decrease, certainly in the upper portion. The gaps through Chestnut ridge, ten miles west from Laurel, afford the last exposures in this direction of any part of the Devonian on the eastern side of the basin; the section in the Conemaugh gap,[2] barely fifty miles in a direct line from Pittsburg, is:

Pocono,	443 ft.
Montrose red shales,	125 "
Lackawaxen Conglomerate,	20 "

[1] Stevenson: Geology of Bedford and Fulton Counties, p. 81.

[2] Geology of Fayette and Westmoreland Counties. J. J. Stevenson, Harrisburg, 1877, p. 291.

Shale and sandstone,	120 ft.
Concealed to river,	150 "

The Montrose shale is composed of dull, grayish red shale and thin streaks of sandstone, carrying Chemung species up to within one foot of the Pocono. The Lackawaxen is characterized by flat-pebbles[1] as it is also on the National road in Fayette county, where some of the larger pebbles are felsyte-porphyry. Excavations made since these measurements were obtained show that there is much dull red shale below the Lackawaxen, especially in the concealed portion. The interval from the top of the Pocono to the Lackawaxen is 568 feet; in the deep boring at Pittsburg it is given as 519 feet.

Mr. J. H. Carll has tabulated the oil-well records in the western oil-bearing counties of Pennsylvania and we must depend largely upon his work as we follow the series northward in western Pennsylvania; though one may sometimes fail to accept his identifications, yet all must acknowledge the patience with which he has worked and the excellence of his results.

At Washington, about thirty miles southwest from Pittsburg, the interval to the Lackawaxen from the top of the Pocono is 518 feet, and the rock is termed by Mr. Carll,[2] the "Gas Sand." The section there is:

Pocono (Shenango sandstone of White),	152 ft.
Interval,	366 "
Lackawaxen Conglomerate,	20 "
Interval,	87 "
Gantz oil sand,	40 "

The Pocono has become less coarse. At Pittsburg it contains much shale, while in Washington county its sandstone is often less than 150 feet thick.

Mr. Carll recognizes in the Gantz sand, the upper or first of the Venango group of oil-sands, which consist of three well-marked sandstones separated by shales and showing few variations in Venango county. It is not easy, however, to accept this identification after a careful study of his sections as tabulated in the Annual Report for 1886,[3] and I am compelled to regard the Upper Gas

[1] An annoying error occurs in my report on the Ligonier Valley (Harrisburg, 1878). Some of the notes referring to this rock were copied under the Pocono and some of the Pocono transferred to this, so that this conglomerate is described as not containing flat pebbles.

[2] Carll in Ann. Report of 2d Geol. Survey of Pennsylvania for 1886, p. 656. See plate 5, figs. 20 and 21.

[3] See Fig. 21 of plate 5.

Sand of Weirick's well as the first oil-sand of Venango and as the Lackawaxen. The distribution and variations of the Venango group are shown in the very numerous records of oil-wells which Mr. Carll has preserved and published in his volumes on the western counties of Pennsylvania. A section on Thorn creek[1] in Butler county, at about thirty miles northward from Pittsburg gives:

Shenango sandstone (of White):

Interval,	395 ft.
[*Lackawaxen*] first Venango oil sand,	45 "
Interval,	420 "
[*Allegrippus*] third Venango oil sand,	46 "

Seven years ago, Professor White asserted that the first oil-sand is the same with his Lackawaxen and suggested that the Allegrippus might prove to be the same with the Third Venango. There is no room for doubt respecting the accuracy of these surmises. The interval between the sands is not far from what we should expect, for in western Bedford it is not more than 600 feet and the decrease in the upper part of the column continues westward to the last exposure under Chestnut ridge. Some red rock occurs in this interval at Pittsburg and at Petrolia in eastern Butler as well as at Edenburg, twenty miles farther east in Clarion county. Red shales, from sixty to more than 100 feet thick overlie the Lackawaxen at many places in Butler county, though occasionally they are separated by a few feet of variegated shale. A section on Bullion creek,[2] in Venango county, about thirty miles north from Thorn creek, shows 100 feet of red rock immediately over the Lackawaxen or first oil-sand and fifty-five feet of red rock in the 215 feet interval between that and the Allegrippus or third oil sand. The distance from the Pocono here to the Lackawaxen is 385 feet, almost the same as in Brady township and on Thorn creek of Butler county.

It is unnecessary to go into further detail respecting the features of the Venango group as the variations aside from those of thickness are inconsiderable and they are all shown in full in Mr. Carll's several reports.

The whole series comes to the surface again in Crawford and Erie, the northwest counties of Pennsylvania, where the subdivis

[1] Carll in Report for 1886, p. 650. See fig. 19, of plate 4. I have condensed the section and inserted the names of the sands.

[2] Carll in *loc. cit.*, p. 647. See plate 3, fig. 14.

ions have been worked out in great detail by Professor White. I give his generalized section[1] somewhat condensed and differently divided:

Pocono:			
1.	Shenango sandstone,	25 ft.	
2.	Meadville shale and limestone,	66 "	
3.	Sharpville flags and limestone,	64 "	
4.	Orangeville shale,	75 "	
5.	Corry sandstone,	20 "	250 ft.
Chemung:			
1.	Cussewago shale and limestone,	37 "	
2.	Cussewago sandstone,	25 "	
3.	Riceville shales,	80 "	
4.	(*Lackawaxen*) first oil sand,	20 "	
5.	Shales with second sand,	260 "	
6.	(*Allegrippus*) third oil sand,	30 "	
7.	Lower Chemung,	325 "	
8.	Girard,	225 "	
9.	Portage,	475 "	1477 ft.

Professor White placed the whole section to the base of the Cussewago in the Pocono or Lower Carboniferous, though seemingly with some hesitation respecting the lower members. The Corry sandstone appears to be the representative of the Berea of Ohio. The Riceville shales are equivalent to the red rock of Butler and Venango as well as to the Montrose red shales of the eastern sections. Typical Chemung forms occur here at many places up to within fifteen feet of the Cussewago sandstone. The Lackawaxen is seldom coarse in northwestern Pennsylvania. The Allegrippus, or third oil sand, is the persistent stratum in this region and the one possessing economic importance. Professor White gives good reason for identifying it with the Panama conglomerate of New York. Professor White found the same section in Warren county at Tidioute, twelve miles east from the Crawford line, and he regards the *Coccosteus* bed at Warren as the same with the Lackawaxen or First Venango oil sand. Mr. Carll's section at Great Bend,[2] on the eastern edge of Warren county, is of interest as showing the appearance of the "Catskill type," as he terms it, there being above the Riceville shales, eighty-eight feet of greenish gray sandstone

[1] Geology of Crawford and Erie counties. I. C. White, Harrisburg, 1881, pp. 66–119.
[2] *Loc. cit.*, p. 641.

with olive and red shales; so that somewhere between Tidioute and Great Bend the typically Catskill characteristics appear in the upper part of the section. Chemung fossils are found in the Riceville shales or Montrose red shales and *Sanguinolites* occurs in the Lackawaxen.[1]

Meanwhile a noteworthy change has occurred below the Lackawaxen, for though 327 feet of rock are shown, yet the Allegrippus or Third sand is not reached; so that we are prepared for the condition shown by Mr. Ashburner's generalized section of McKean county, next east to Warren along the northern border of the state. There we find[2]

Pocono,	250 ft.
Catskill,	250 "
Chemung,	1990 "

the Catskill consisting of "red and gray slate, shale and sandstone" at Smethport, thirty miles east from Great Bend in Warren county. The Chemung is triple and its upper division is itself distinctly triple, consisting of:

Gray shale and sandstone,	350 ft.
Red and gray shale and sandstone,	300 "
Gray shale and sandstone,	650 "

the lowest beds resting on the Bradford oil sand, which is Mr. Ashburner's Middle Chemung. Typical Chemung mollusks occur in the highest beds of the Chemung and some species appear to have persisted into the lower portion of the beds assigned to the Pocono. This abrupt thickening of Chemung and Catskill is precisely what should be expected here to accord with the conditions along the southern border of the state.

The sections in Potter county, that adjoining McKean at the east, are incomplete and our knowledge of the structure is far from being satisfactory. Mr. Ashburner made some examinations in the western part of the county, which were merely incidental and suffice only to show that the "Catskill type" of rock increases in thickness eastward just as it does toward the southeast, there being 370 feet of red, gray and green shales and sandstones overlying the uppermost subdivision of his McKean county Chemung.[3] He finds some red in his Chemung as well as in the overlying Pocono.

[1] Geological Report on Warren county. J. H. Carll, Harrisburg, 1883, p. 302.
[2] Geology of McKean County, etc. C. A. Ashburner, Harrisburg, 1880, p. 43.
[3] *Loc. cit.*, pp. 77-78.

Fish beds occur in his Catskill as well as in the upper part of his Chemung. No information is given respecting distribution of molluscan remains, but on the eastern side of Potter, Chemung forms extend far up into the red beds, for just over the border in Tioga county, Chemung forms are found at more than 300 feet above the first red beds.[1]

The condition in Tioga and Bradford counties, those next at the east, is sufficiently clear. Professor White's incidental studies in those counties make it possible to utilize Mr. Sherwood's work and at the same time to gain a good understanding of the work done by Professor Hall and Mr. Vanuxem more than fifty years ago. The section near Blossburg, in Tioga county, gives a good starting point.[2] It is:

Pocono,	573 ft.
Red shales, green and gray sandstones and concealed,	830 "
Fish conglomerate (*Holoptychius bed*),	2 "
Red shale and sandstone,	200 "

The thickness of the rocks in the vicinity of Blossburg had been much underestimated by other observers. All the beds of the section below the Pocono have been regarded by authors as Catskill; but at ten miles farther down the Tioga river, three miles below Mansfield, Chemung fossils have been found by Mr. Sherwood[3] in a calcareous rock, only 165 feet below the bed taken as the base of the Pocono in Professor White's section and therefore at more than 950 feet above the lowest red beds in that section. At a little way farther east, Mr. Sherwood found great abundance of fish remains with shells and fragments of plants in the *Holoptychius* bed; a calcareous bed at 84 feet lower down contains abundance of well-known Chemung forms, while red beds continue in alternation with gray beds for 150 feet lower down in the column. In 1839, Professor Hall connected his New York work with Pennsylvania at Tioga, eight miles farther down the river, where he found the upper member of the Chemung passing under the Old Red Sandstone, whose thickness he estimated at 400 feet. It is

[1] A. Sherwood in Report of Progress in Bradford and Tioga Counties. Harrisburg, 1878, p. 86.

[2] Geology of Susquehanna and Wayne Counties. I. C. White, 1881, p. 72.

[3] Sherwood: *loc. cit.*, p. 79.

sufficiently clear that the red beds, including the Fish Bed, were regarded by him as belonging to the "Old Red Sandstone."

The McKean county section can be recognized without difficulty in Tioga county despite the change in character of the rocks; for the middle division of Mr. Ashburner's Upper Chemung finds its equivalent in the "Mansfield Beds" of Lesley, containing three ore beds near Mansfield, the second of which is the celebrated *Holoptychius* bed. The base of the Red and Gray group in McKean is at 900 feet below the Pocono while in Tioga county the *Holoptychius* bed is at 830 feet. At the same time, the structure so well worked out by Professor White in Susquehanna county can be recognized with less difficulty than that of McKean. Eastward from the Tioga river, fossils become rarer in the upper part of the section; Mr. Sherwood states that no fossils occur in the Towanda basin of Bradford county until a bed is reached at 800 feet below the Pocono.[1]

Professor White's work in Susquehanna and Wayne counties, was connected by him with that in Bradford, which lies between Tioga and Susquehanna. His section for those counties,[2] condensed and re-arranged is

Catskill:	
Cherry Ridge shales,	110 ft.
Honesdale sandstone,	90 "
Chemung:	
Montrose red shales,	180 "
Paupack sandstone and shales,	
New Milford flags and shales,	585 "
Shales and sandstones,	244 "
"Mansfield Reds,"	90 "
[*Allegrippus*] Cascade Creek sandstone,	25 "
Shale and sandstone,	120 "

The lower portions of the column are not exposed in these counties. The Paupack sandstone, immediately underlying the Montrose shales, occupies the position of the Lackawaxen conglomerate, but it is not seen as a conglomerate except in eastern Wayne on the border of Pike county. The Cascade creek sandstone is the

[1] *Loc. cit.*, p. 28.

[2] Geology of Susquehanna county and Wayne county. I. C. White, Harrisburg, 1881, pp. 56, 58, 59, 73. In accordance with Professor White's suggestion (Geol. of Susquehanna R. Region, p. 52), I have omitted the upper 375 feet of the section.

same with the Falls creek sandstone of Bradford county and with the Allegrippus conglomerate of Bedford and Huntingdon counties, the Lower Chemung conglomerate of Fulton county. A great part of the interval between these sandstones is represented farther east by the Delaware flags. For the most part, this is the section observed along the Delaware river in Pike county of Pennsylvania and in the adjacent portion of New York; and the Honesdale sandstone is the Montrose sandstone of Vanuxem.[1] Professor White made diligent search for fossils, but no mollusks were found at any horizon more than 130 feet above the Allegrippus; but Chemung fossils are sufficiently abundant below that rock. *Archæopteris jacksoni* occurs in the Paupack or Lackawaxen.

III.

We have come once more to the Delaware river, the last point reached in the tracing of the easterly outcrop. Clearly the series is one; the middle portion, that between and including the two conglomerates, is evidently persistent all the way round, except, perhaps, in McKean and Potter counties of Pennsylvania where, however, the difficulty lies most probably not in absence of the subgroup, but in the absence of records.

The serious question now arises—How shall this great column, with a maximum thickness of more than 7000 feet, be divided and what value shall be assigned to the divisions? Before undertaking to answer the question, let us recall the signification of the terms Catskill and Chemung as originally employed.

Mather in the annual report as well as in his final report[2] used the term "Catskill Mountain Series" to include all beds from the very highest rocks in the Catskill Mountains down to the Corniferous, thus making it equivalent to "Formations VIII, IX, X and XI of Professor Rogers' Report on the Geology of Pennsylvania for 1838." "Catskill Group" was used first by Vanuxem in his final report, published in 1842,[3] though he had previously fixed the lower limit as may be seen by reference to the fourth report, where he takes the Montrose sandstone as representing the group. That rock rests directly on the Chemung group, whose upper limits are not well defined in the Fourth district of New York though

[1] Annual Report of N. Y. Survey for 1839, p. 381.
[2] Fourth Annual Report, p. 227. Geology of N. Y., Part I, p. 299.
[3] Geology of New York, Part III, p. 186; 4th Ann. Rep., p. 381.

sufficiently so in the Third. Its lower boundary appears to be distinct in both, so that the group consisted of the Chemung and Portage. But the Catskill group of authors is a variable quantity. By some, the whole mass in the Catskills proper has been taken as belonging to the group; by others, the first red bed is taken as the base of the group, while others still see the beginning in the first fish bed. No one of these limitations suffices, for each is purely local in character and cannot be applicable over a great area.

Stratigraphically, the two groups as understood by Vanuxem are separable without difficulty. The Catskill, including under that name the Cherry Ridge shales of White and the Montrose sandstone of Vanuxem, is thoroughly persistent along the eastern outcrop from Greene county of New York to far beyond the James river in Virginia; its variations in thickness along this line are, for the most part, very similar to those of the upper and middle divisions of the underlying Chemung. Westward and northwestward, however, the variations of the Catskill are unlike those of the Chemung. In southern Pennsylvania, the Cherry Ridge shales disappear within forty miles, while the Montrose sandstone thins out more slowly and does not disappear until Fayette county is reached; there, however, the whole mass, 3700 feet thick in Fulton county, is wanting. In northern Pennsylvania, the decrease in thickness is abrupt for a few miles, but the final disappearance of rocks of the Catskill type is in Warren county, just as in New York it is in Allegany county east from the Genesee river.[1] In southwest Pennsylvania the Catskill is wanting, because the rocks have thinned out; whether the disappearance in northwest Pennsylvania is due only to thinning out or to interlocking with rocks of different color cannot be determined in our present state of knowledge.

The upper subdivisions of the Chemung, when followed westward, are found to vary much after the manner throughout. The abrupt changes observed in the Catskill had no predecessors in the Chemung, except in southwestern Virginia, where the whole series Chemung and Catskill, as well as most of the underlying Hamilton and much of the overlying Pocono have disappeared. The Chemung section thus grouped

[1] Geology of New York, Part IV, p. 279.

Shales
Sandstone
Shales and sandstone
Sandstone
Shales and flags

can be recognized not merely along the eastern outcrop from New York to far beyond New river in Virginia but also in western Pennsylvania many miles beyond the western limit of the Catskill beds.

It is sufficiently clear that at the close of the time embraced in the Chemung group a physical change occurred, which though not observable along the eastern outcrop becomes very distinct within 100 miles westward or northwestward. During the whole of the Chemung period the subsidence was less and less rapid toward the west and northwest, though doubtless keeping pace there as at the east with accumulation of deposits, which in that direction became less in quantity and finer in grain, as the rocks at the west and northwest were not such as to yield much coarse material. But at the close of the Chemung, the subsidence became still less rapid toward the west and northwest so that the area in which Catskill was deposited became narrower toward the south.[1] It is altogether unnecessary to resort to the conception of elevation in western Pennsylvania or Virginia; indeed any such conception would be at variance with such evidence as we have. That region was not above water at any time so as to make the Catskill deposit in a closed sea; no subaërial erosion took place there after the close of the Chemung, for the thickness of Montrose shales in the oil-wells and in northwestern Pennsylvania, where they are Professor White's Riceville shales, varies immaterially from their thickness in Somerset county, where they underlie the western edge of the Montrose or Honesdale sandstone.

But while making use of these variations in rate of subsidence as affording a convenient method of separating the Catskill and Chemung groups, we must not forget that, in by far the greater part of the area, the conditions exhibited in the Catskill are but a continuation and as it were an intensification of those existing in the Venango portion of the Chemung. The appearance of red rock with green and greenish gray sandstone begins in Pennsylvania

[1] Because of the southwestward trend of the Appalachian land area.

very little above the Allegrippus conglomerate, and continues in irregularly increasing quantity to the top of the column, while in New York, red rock makes its first appearance in the Portage.[1]

The amount of red rock between the conglomerates varies greatly, being seldom more though often less than ten per cent along the eastern outcrop, while at some places in western Pennsylvania it is much greater. The Montrose shales are largely red along the eastern outcrop, but they show not a little variation there; while at the west, they are sometimes wholly red and at others without any red beds whatever. Greenish gray and brown or reddish brown sandstone occurs in large proportion in the Catskill itself.

All observers agree that the passage of Chemung into Catskill is so gradual that lithologically no absolute line of separation can be drawn in a great part of the Appalachian basin. The bond between Catskill and Upper Chemung is even more intimate, as far as structure goes, that is that between the Upper Chemung and the Lower Chemung or Portage. As far as physical characteristics are to be depended on, the whole series is one, and the terms

Catskill
Chemung
Portage

might well be taken as names of epochal divisions of the Chemung period.

The palæontological record confirms this conclusion drawn from study of the stratigraphy. For the most part, the changes in general conditions were insignificant from the beginning of the Portage to the close of the Chemung; at all events the changes, in by far the greater part of the area under consideration, were not such as to interfere materially with the existence of the molluscan fauna known as Chemung, though as we have seen, there were circumscribed areas in which the conditions did prove very injurious to animal life.

The Chemung and Catskill are very distinct palæontologically along the eastern outcrop in southern Pennsylvania. The Catskill, almost wholly red shale and red or greenish gray sandstones, appears to be wholly non-fossiliferous; but the Chemung carries its fossils to practically the top of the Montrose shales. The condition is unquestionably the same in northern Virginia. Near the Tennessee border, the equivalent of the Montrose sandstone has

[1] James Hall in 28th Annual Report of the Regents on the State Museum, 1876, p. 15.

Chemung fossils; at New river gap, Chemung fossils were not found in the upper half of the interval between the Lackawaxen and the Pocono; in McAfee's gap in Roanoke county, proof is shown that *Spirifera disjuncta* survived all changes to the end of the Catskill; while at eight or ten miles southeast in Catawba mountain, the whole succession of greenish gray sandstones seems to be absolutely non-fossiliferous; and this is the prevailing condition thence northward. It is evident then that from say twenty-five miles southwest of James river in Virginia to New York, the group called Catskill by Vanuxem is either non-fossiliferous or practically so. But the Chemung group contains its characteristic species above the Lackawaxen Conglomerate in Virginia and along the eastern outcrop into Montour county of Pennsylvania; so also in southern Pennsylvania[1] westward to where it passes beneath the surface beyond the final disappearance of Catskill in Fayette and Westmoreland counties; while in northwestern Pennsylvania and along the northern line of the state Chemung forms are present in the same upper horizon from the Ohio line eastward into Bradford county. In New York on the northwest border of the Catskills themselves, Chemung fossils[2] occur abundantly above the Oneonta sandstone, which Vanuxem identified with the Montrose sandstone of Pennsylvania.

A remarkable feature of the Chemung is the non-fossiliferous area of southeastern New York and the adjacent portion of Pennsylvania. Northward from Huntingdon county of Pennsylvania, the upper limit of the Chemung fauna descends; in Columbia county the upper half of the Montrose red shales yields no fossils, while in Carbon county, no fossils were found until practically below the place of the Allegrippus Conglomerate; and even in these lowest beds, fossils are rare and usually not well preserved. No molluscan fossils were found by Professor White in the Delaware river section until considerably below the place of the Allegrippus, whence downward "the whole series is sparingly fossiliferous."[3] Even the remains of fishes are wanting aside from "the occasional appearance of what appear to be fish-bone fragments in calcareous breccias." A similar condition is observed as one comes east-

[1] In my Report on the Geology of Bedford and Fulton counties, p. 81, I identified the Conglomerate of the Laurel and Chestnut ridge gaps with the Lower (Allegrippus) Conglomerate. The error was discovered too late for correction.

[2] James Hall in Science, 1880. p. 290.

[3] Geology of Susquehanna River Region, pp. 103 and 105.

ward along the border of Pennsylvania and New York: Chemung fossils reach the top of the group at the western border and in McKean county; but in Tioga county the barren space at the top of the column is 165 feet; in Bradford, 800 feet; in Wayne, 1170; and in Pike, 2650 feet; in each case inclusive of the Catskill which, however, does not exceed 300 feet even in Pike county.

The area in which the lifeless portion of the column reaches much below the horizon of the Lackawaxen Conglomerate, embracing parts of Carbon, Monroe, Pike and Wayne counties of Pennsylvania and Sullivan, Delaware and Greene counties of New York, contains rather more than 4000 square miles, while the whole area under consideration is more than 30,000 square miles. To explain the absence of life is not easy; it cannot be due merely to an agent which caused the redness or greenness of the beds, for in Huntingdon and Fulton counties of Pennsylvania the Montrose shales have many fossiliferous beds though having also many green and red beds. Besides, the Delaware section shows a great thickness of beds of other colors, which are equally without animal remains. It cannot be due to chemical conditions existing in a closed sea, for the successive subdivisions of both Catskill and Chemung can be traced directly into the lifeless area equally from the open sea at the west and along the Appalachian shore from the south, thus showing that no closed sea existed in that area. Even plant remains are rare, being found at but few localities; and as a rule the specimens are imperfect, good specimens occurring at only a very few places. There is little room to suppose from the condition in which the plants are found that alternations of land, fresh and brackish water conditions caused the absence of animal life. It is certain that from the beginning of Oriskany to the end of Catskill, even during the formation of the Corniferous coral reefs, the Appalachian gulf was shallow everywhere. During the latter time, when subsidence did little more than to keep pace with the inflow of sediment, the area nearest to the region of great drainage, whence large streams with rapid flow poured their material into the shallow basin, would show muddy bottoms and muddy, more or less brackish water which would be unfavorable to animal life of Chemung types. As the Appalachian land became narrower southward, the untoward conditions are less marked in that direction. Within the portion of the area lying within southeastern New York and the immediately adjacent portion of Pennsylvania

these conditions may have been begun as early as the Hamilton, as suggested by Professor Hall.[1]

The molluscan fauna of the Chemung and Catskill is unquestionably marine. Even the mollusks found in New York above the Oneonta sandstone belong to the ordinary forms. Of course it is possible, even probable, that at the extreme northeast there were small areas at the mouths of large rivers where fresh water prevailed and fresh-water mollusks lived; but positive evidence of this is wanting. The *Amphigenia* found in the Oneonta sandstone of New York may be a fresh-water form, but it occurs in the Montrose sandstone in southern Pennsylvania so far away from the old shore line that fresh-water conditions seem, certainly, improbable.

The stratigraphical relations of the fishes have been generally misunderstood. The fishes exist, for the most part, not in the Catskill but midway in the Chemung; the celebrated *Holoptychius* bed is the second of the ore beds of the "Mansfield Red" and belongs at but a little way above the Allegrippus Conglomerate, the Falls creek sandstone of Bradford county. It has yielded large numbers of fish remains at several localities and it contains marine fossils.[2] The *Coccosteus* bed of Warren county is taken by Professor White to be the same with the First Venango sand (Lackawaxen Conglomerate). Wherever the fishes are associated with any other form of animal life, that form is marine, so that the ordinary presumption should be that the fishes themselves are marine.

A study of the fauna and its distribution shows us that, as far as any evidence exists, the conditions were marine from the beginning of the Chemung period to the close of the Catskill; that in the early Chemung or possibly in the Hamilton the conditions within northeast Pennsylvania and the adjacent portion of New York became unfavorable to the free development of animal life; and that as time went on, these conditions were gradually extended southward and westward, so that toward the close of the Chemung, they prevailed in Columbia county, fifty miles southeast from the Delaware river and in Bradford county, about the same distance west from the outcrop line. Before the close of the

[1] Science, 1880, p. 290. Prof. H. S. Williams makes the same suggestion in Bulletin U. S. G. S., No. 41, but I have mislaid the reference.

[2] Sherwood in Report on Bradford and Tioga, pp. 63, 65, 79, 80.

Catskill they had reached southward beyond James river in Virginia but had not extended much farther west in Pennsylvania and New York. But while prevented from existing in the muddy shallows, the animals existed farther west in the basin beyond reach of the river silts just as soon as an opportunity was afforded by a lull in the untoward conditions, the active fishes found their way eastward again to be followed, if the interval were long enough, by the more sluggish mollusks as in New York and in Roanoke and Russell counties of Virginia.

One matter still remains. A few words concerning it and I have done.

What are the relations of this great Chemung-Catskill group to the Lower Carboniferous?

The Pocono or Vespertine or Lower Carboniferous sandstone, the division of the Lower Carboniferous, is practically non-fossiliferous throughout central and southern Pennsylvania, the only animal remains thus far discovered being those of mollusks, seen by Professor White[1] in Bedford county, Pennsylvania and those of fishes seen by Professor Stevenson[2] in Fayette county; but these have not been studied and their relations are still unknown. The upper beds of the Pocono become calcareous in southwest Virginia where the mollusks are unquestionably Lower Carboniferous. The plant remains, obtained in Pennsylvania, are for the most part imperfect, but an abundant flora exists near New river in Virginia, which has been collected by Mr. R. D. Lacoe. It has not been been studied in detail, but enough has been ascertained to show that its facies is Devonian rather than Carboniferous.[3] The Lower Pocono in Pennsylvania, containing thin coal beds, may prove to be the same with the series near New river, which disappears altogether before the state line is reached at the south.[4]

The molluscan fauna of the Chemung shows no intimate relation to that of the Lower Carboniferous. True, not a few carboniferous types make their appearance in the Chemung, but in like man-

[1] Geology of Huntingdon County, p. 81.

[2] Geology of Ligonier Valley, p. 57.

[3] J. P. Lesley in a Dictionary of Fossils found in Pennsylvania and Elsewhere, Vol. III, Addenda, p. xiii.

[4] It is worth noting here that during the study of Wayne and Susquehanna counties, Professor White placed the upper limit of Catskill nearly 400 feet higher in the column than he did in his later publications. It is not at all improbable that his original plane of division may prove to be the proper one for the whole eastern outcrop to beyond New river.

ner some Devonian types make their appearance in the Upper Silurian. The plant remains of the Chemung show somewhat greater affinity to the Carboniferous, but there is not enough of the material to justify positive conclusions in any direction; at the same time these plants are closely allied to the Erian flora of Canada, occupying a somewhat similar position in the general column.

The physical break between Pocono and Catskill seems to be sufficiently well-marked at most localities along the eastern outcrop, as well as along the southern border of Pennsylvania; so that where Pocono and Chemung go beneath the surface they are sharply separated. The Pocono goes under in Fayette and Westmoreland counties of Pennsylvania as a sandstone containing very little shale; but when it reappears in northwestern Pennsylvania, in Crawford county, it is sandstone on top with much shale below, so that the separation from the underlying Chemung is by no means so distinct. Professor White, in making his correlations with Ohio, found difficulty in determining the equivalents of the Cleveland and Bedford shales of that state, which were regarded then as belonging to the Waverly or Lower Carboniferous. But Prof. Edward Orton, several years ago, found it necessary to place the Cleveland shales in the Devonian: and still more recently, Professor Herrick's detailed studies have shown that the Bedford shales carry the Chemung fauna, as was suggested many years ago by Professor Hall. But, beyond all doubt, the lower portion of the Pocono in Crawford county shows an unexpected relation to the Devonian,[1] for at about two hundred feet below the Shenango sandstone, there is a persistent limestone, which, though non-fossiliferous in Crawford, carries many fossils in Warren and Venango counties. It is found also in McKean. The fossils from Warren and Venango have not been studied but Professor White says that one of the *spirifers* suggests *S. disjuncta*. Chemung forms occur at the base of the Corry sandstone, which Professor White thought to be the equivalent of the Berea grit of Ohio. In McKean county[2] Professor Hicks found Chemung forms passing up into the Mauch Chunk or upper division of the Lower Carboniferous and associated there as well as in lower beds with "Waverly forms," seven Chemung species having been found with seven

[1]White: Geology of Crawford and Erie Counties, p. 88.
[2]L. E. Hicks in Report on Geology of McKean County, pp. 30-31.

determined and eleven undetermined species regarded by him as of "Waverly type." Prof. H. S. Williams has shown, in his discussion on the Fossil Faunas of the Upper Devonian,[1] that, at some localities in southwestern New York and northwestern Pennsylvania, species belonging to the Chemung fauna lingered even into the shales underlying the Olean conglomerate, which is the floor of the Coal Measures. It is sufficiently clear that while the passage from Devonian to Carboniferous along the eastern outcrop and for many miles west and northwest from it was marked by great physical changes, no serious disturbance occurred in the region of northwestern Pennsylvania and the adjoining portions of New York and Ohio, where the passage was so gradual as to permit the Chemung fauna to overlap that of the Lower Carboniferous. But the fact that at some locality or even in a somewhat considerable area the passage from Chemung to Carboniferous is not marked by abrupt change in sedimentation and by a sharp limitation of faunas is not a good reason for embracing Chemung in Carboniferous. Other portions of the Appalachian region might be selected which would afford material for very different generalizations.

If continuity of sedimentation is to be accepted as of itself a good basis for grouping rocks, one would be compelled, within a considerable area of Virginia, to include in one age all rocks from the Hudson river shales to the top of the Pocono, for there one finds no interruption, except a streak of Lower Helderberg, so thin, that only one observer[2] has seen it in place, though others have seen fragments of chert suggesting the presence of that group. Nor is the fact that there are localities where the passage is not abrupt, is not marked by destructive fauna, necessarily a good reason for joining two consecutive groups. On such a basis one would have no difficulty in carrying the Carboniferous downward so as to include the Lower Silurian or upward to include the Pliocene. Thus in northwestern Pennsylvania, the Chemung fauna lingered into the Lower Carboniferous; in south central Pennsylvania and Maryland,[3] Oriskany and Lower Helderberg fossils are mingled together in a transition bed. Ordinarily the break between Lower and Upper Silurian is well marked; but, in southern Pennsylvania,[4]

[1] H. S. Williams: Bulletin of the United States Geological Survey, No. 41, Chapter IV.

[2] Capt. C. R. Boyd, in personal communication.

[3] Stevenson: Geology of Bedford and Fulton Counties, p. 86.

[4] *Loc. cit.*, p. 92.

the Hudson river forms occur sparingly in the Lower Medina, while in southwest Virginia[1] Hudson river fossils occur abundantly to within a few feet of the Upper Medina; so that even on the easterly side of the Appalachian basin it would be easy to prove no break between Lower and Upper Silurian, Upper Silurian and Devonian, Devonian and Lower Carboniferous, Lower and Upper Carboniferous. Dr. C. A. White[2] has told us how the line between Palæozoic and Mesozoic disappears in the southwest; while, to not a few of us, the gradual shading away of Mesozoic into Cenozoic brought a sufficiency of burdens in the past. General, not circumscribed conditions must be taken as the basis of subdivision of the column. The separation between Lower Carboniferous and the Upper Devonian is too well marked physically as well as palæontologically over an immense area to be ignored for any but the most cogent reasons.

But may not the Catskill as well as some portion of the Chemung be contemporaneous with the lower beds of the Lower Carboniferous of Ohio? Professor Herrick[3] has shown that the base of the Lower Carboniferous there cannot come below the Berea Grit. He has shown also how intimately related the Bedford shale is to the underlying Cleveland-Erie shale and that forms of Lower Carboniferous type made their appearance only toward the close of the former, so that here the faunas overlap as in northwestern Pennsylvania. It is possible that when the detailed revision of the Devonian column has been carried across from eastern New York by Prof. H. S. Williams into Ohio, the beds of the Catskill will be found interlocking with beds of other tints, which in Ohio become the Bedford and Cleveland shales. If we bear in mind these facts:

First, that the Chemung and Catskill deposits were laid down in a shallow basin subsiding most rapidly at the east and along a line rudely parallel to the Blue Ridge trend;

Secondly, that the deposits would be much greater near the mainland at the east than at two hundred miles away; so that six hundred feet more or less of fine material in Ohio would more than fairly represent the four thousand feet of Chemung in eastern Pennsylvania; and

[1] Stevenson: Proc. Amer. Phil. Soc., Vol. XXII, p. 138; XXIV, p. 85.
[2] C. A. White: Address as vice president before Section E of A. A. A. S., 1889.
[3] C. L. Herrick: Bulletin Geological Society of America, Vol. II, p. 34 seq.

Thirdly, that the water beyond the reach of the great land wash held a Chemung fauna throughout the whole time of the Catskill deposit; there will be no serious difficulty in the way of accepting these suggestions.

The conclusions to which I am led are:

First, that the series from the beginning of the Portage to the end of the Catskill forms but one period, the Chemung, which should be divided into three epochs: the Portage, the Chemung, and the Catskill.

Secondly, that the deposits of the Catskill epoch were not made in a closed sea or in fresh-water lakes.

Thirdly, that the disappearance of animal life over so great part of the area toward the close of the period was due to gradual extension of the conditions existing in southeastern New York as early, perhaps, as the Hamilton period.

Fourthly, that the Chemung period should be retained in the Devonian.

PAPERS READ.

POST-GLACIAL ANTICLINAL RIDGES NEAR RIPLEY, N. Y., AND NEAR CALEDONIA, N. Y. By G. K. GILBERT, United States Geological Survey, Washington, D. C.

[ABSTRACT.]

AT the Buffalo meeting I presented to the Association an account of post-glacial anticlinal ridges observed in northern New York and northwestern Ohio. The ridges are small, having a width of a few rods and a height of a few feet, the maximum height observed being sixteen feet. In northern New York they are constituted of Trenton limestone, in northwestern Ohio of Devonian shale. They are chiefly or entirely within areas thinly covered by till overlain by laminated lacustrine clay of the Champlain epoch.

At Buffalo I expressed the opinion that the phenomena are superficial, basing that inference on the narrowness of the ridges. I am now able to sustain the inference by reporting a section which extends well toward the base of one of the disturbances. The locality was first mentioned by James Hall in the Geology of the Fourth District of New York. Near Ripley the shore of Lake Erie presents a cliff toward the lake, and this cliff, about forty feet in height, exhibits a ridge in section. The amount of disturbance and the width of the disturbed area diminish from the top of the cliff to the base at so rapid a rate as to indicate that the disturbance extends but a few feet below the water level.

Mr. E. E. Howell reported to me the occurrence of similar phenomena at Lime Rock, between the towns of Caledonia and Le Roy, New York, and I afterward visited the locality. A great number of small anticlinal ridges are there to be seen and they are post-glacial, but they differ in type from those previously described and they probably differ in origin. They run, as a rule, parallel with one another and with the strike of the strata. The anticlinals are usually unsymmetric and the disturbed rock is greatly fractured. The ridges are much nearer together than those of other localities. The local rock is Carboniferous limestone and beneath it are shales of the Salina group. A few miles to the northward the drill has discovered a bed of salt in these shales. The theory advanced in explanation is that salt and gypsum are being removed from the shales somewhat rapidly by underground water, that the superjacent Corniferous limestone

sinks in large masses, and that the ridges are the superficial phenomena of the partings of these blocks. A large spring issuing from the limestone is exporting annually more than 300,000 cubic feet of salt and gypsum.

THE ALTITUDE OF THE EASTERN AND CENTRAL PORTIONS OF THE UNITED STATES DURING THE GLACIAL PERIOD. By Pres. T. C. CHAMBERLIN, U. S. Geological Survey, Madison, Wis.

[ABSTRACT.]

I. The absence of coarse glacio-fluvial deposits in the lower Mississippi. The wide extent and present high altitudes of the glacio-fluvial silts of the early glacial period. The low position and the character of the glacial deposits of the later glacial epoch. Conclusions drawn from the phenomena of the lower Mississippi valley.

II. Phenomena of the drift border.

The attenuated character of the drift margin; its significance respecting surface slope. The absence of coarse gravel trains issuing from the border. The gradation of the drift sheet upwards into glacio-natent silts. Conclusions springing from these phenomena.

III. The smooth contours of the older morainic ridges.

The aprons of silt that flank these on the outer side. The relation of these aprons of silt to the river valleys. Conclusions drawn from these phenomena.

IV. The characteristics of the later terminal moraines.

Their more irregular topography and coarser constitution. The over-wash aprons and the valley trains of sand and gravel. The relations of these over-wash aprons and the valley trains to the present channels of drainage.

V. Phenomena of the later moraines.

Less vigorous drainage at the time of formation of the latest moraines. Conclusions drawn from these phenomena.

VI. Lacustrian and marine phenomena.

Significance of these.

VII. General conclusions.

THE CINCINNATI ICE-DAM. By FRANK LEVERETT, U. S. Geological Survey, Madison, Wis.

[ABSTRACT.]

FOR some eight years the theory has been before the scientific world that the great ice-sheet bridged the Ohio river near Cincinnati, Ohio, sufficiently to block its channel and raise the waters above the place of bridging to a height of 500 to 600 feet above the present river bed. Silt deposits

east of Cincinnati near the ice margin have been cited as evidence of this dam since they stand about 600 feet above the Ohio. These silts have been found by the writer to be too widespread to admit of this explanation since they extend west past Cincinnati, covering much of southern Indiana as well as portions of states farther west. They are also of later date since they rest upon the drift deposited by the ice when it bridged the Ohio and are separated from it by a considerable time interval, shown by humus stain, leaching of till and erosion of surface of the underlying drift.

The apparent absence of striæ south of the Ohio river and the meagre amount of drift there indicate a thin ice-sheet with feeble movement.

These facts and a comparison with other districts where conditions for damming appear to have been more favorable than on the Ohio, lead to the conclusion that the river would not be blocked except for very brief periods.

ON THE PROBABLE EXISTENCE OF A SECOND DRIFTLESS AREA IN THE BASIN OF THE MISSISSIPPI. By Prof. ROLLIN D. SALISBURY, Madison, Wis.

[ABSTRACT.]

THE driftless area of the upper Mississippi valley has attracted wide attention. Even before the critical study of the drift was begun and before its significance was suspected, geologists had recognized the fact that the surface of the area now known as "driftless" was very unlike that of the surrounding territory. The difference which found especial mention in the early references to the area was the absence of transported material. But a not less obvious difference between the driftless area and its contiguous territory consists in its topography. It has notably more relief within narrow geographic limits than has the surrounding drift covered country, and its topographic forms are those developed by subaërial erosion, in contrast to those developed by the agencies which produced the drift. The area is lower than much of the surrounding country, and its anomalous position in the axial portion of the largest hydrographic basin which the ice invaded, has excited much comment and given rise to much speculation as to its cause.

Aside from this driftless area, other areas along the margin of the drift have sometimes been called "driftless." These areas occupy the reëntrant spaces between the lobes which marked the ice front. They differ from the driftless area in being but partially surrounded by drift.

Until the present season, the driftless area of Wisconsin, Illinois, Iowa and Minnesota was supposed to be entirely unique, but the present summer's work has developed the probable fact that a second driftless

area exists. In this case, it was not the absence of drift which first attracted attention as in the area earlier known, but the topography.

The second driftless area lies principally in Illinois between the Mississippi and Illinois rivers, a short distance above their junction. Strangely enough, it does not extend to the point of juncture of the two streams, for the southern end of Calhoun county, where the upland between the two rivers is only two or three miles wide, was overspread by ice. The area here mentioned is therefore completely surrounded by drift.

The precise limits of this second driftless area have not been determined throughout its entire extent, but its general form and its approximate boundaries are known. It comprises the larger part of Calhoun county, Illinois, and the southern part of Pike. Its area is therefore small compared with that of the area to the north. Like the northern area, it perhaps includes, in addition to the area specified, a narrow belt of land on the west side of the Mississippi. It was the topography on the Missouri side that first attracted attention. Near Clarksville, Painesville, and further south, there are here a series of remarkable mounds of almost mountainous proportions, which by their form, at once suggest the mounds which characterize the driftless area farther north (the Blue mounds of Wisconsin). Their significance lies in the fact that they indicate the absence of any considerable ice erosion.

The Illinois portion of this new driftless area is 300 ft. or more above the rivers between which it mainly lies. With this relief, and with its immediate proximity to the great valleys on either hand, the topography is necessarily very broken, in keeping with the driftless character of the area. It is to be borne in mind, however, that the topography of the country immediately adjacent to the Mississippi and Illinois rivers in this latitude, is uniformly a strongly accentuated erosion topography, even where drift is present. It is only a little more strongly accentuated here than elsewhere, where the altitude is comparable.

The region is covered with loess for the most part, often heavily covered. If therefore drift were present beneath it, and especially if present in but small quantity, the determination of its presence might be attended with some difficulty.

The hypothesis that the area is covered by a very meagre sheet of drift, which is concealed by the loess, has been considered and abandoned. There are frequent erosion valleys and ravines, which in recent times have cut through the loess, and reveal the material which lies beneath. In the incoherent material subjacent to the loess, drift has not been found. Hundreds of fresh natural exposures have been examined, and it is on the testimony of these exposures that the area is regarded as driftless.

The hypothesis that the region was originally covered by glacial drift, and that it was removed by erosion before the deposition of the loess, has also been considered and likewise abandoned. The material subjacent to the loess, as now exposed, is frequently incoherent gravel or sand (of preglacial age) of such a character as to be easily eroded. Its presence

beneath the loess is nearly constant throughout the area, except where slopes are very steep. But with it or above it no evidence of glacial drift has been found, and on the summits, where best developed, these gravels and sands do not show any sign of the disturbance to which an incursion of ice would have subjected them. It might well be that where declivities are great, pre-loessial erosion could have removed the drift had it been present. But the sections examined are not confined to slopes. On the summit plains numerous natural sections, and fresh well sections, give constant testimony that drift is wanting. The hypothesis of pre-loessial removal of the drift was therefore abandoned. We seem reduced, in consequence, to the necessity of regarding the area as strictly driftless, in the sense that it was never overspread by ice.

On all sides of this second driftless area the drift covered country affords corroboration evidence of the truth of this position. As the driftless tract is approached from whatever direction, the drift becomes attenuated to an extreme degree, exactly as on the northern, western and southern borders of the larger driftless area to the north. The attenuation may appear to be more extreme than it really is, because of the mantle of loess or loam which conceals the drift proper. Yet sections are frequent enough to establish the fact that the drift becomes very thin on all sides of the area, and that the attenuation increases progressively as the driftless area is approached.

The testimony of the topography surrounding the driftless area is harmonious with that of the attenuated drift border. As the driftless region is approached the topography gradually loses the characteristics developed by ice wear, and the features developed by subaërial erosion take their place. This change in topography is coincident with the thinning of the drift. Before the border of the drift which surrounds the driftless tract is reached, the drift ceases to express itself in topographic forms.

Instead of destroying its uniqueness the recurrence of a phenomenon, heretofore regarded as standing entirely alone, in an equally anomalous geographic position, would seem to mark it as doubly unique.

NEOCENE AND PLEISTOCENE CONTINENT MOVEMENTS. By W J McGEE, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

RECENT investigations in the Coastal plain and Piedmont plateau of eastern and southeastern United States have permitted clear definition of a series of uncomformable formations in the former province, and a series of land forms definitely recording certain continent movements in the latter province; and from the two records combined a presumptively complete history of continent movements in southeastern United States has been read. In brief this history is as follows: From late Cretaceous to

mid-Neocene the land stood low but oscillated from time to time, the amplitude of oscillation being little if any more than 500 feet; during this long period the Piedmont region and the intermontane portions of the Appalachian region were planed to a baselevel; and during the same time-interval three well defined unconformable formations were laid down in the Coastal Plain, each unconformity being of such form as to indicate baselevel planation during the degradation episode. During the later Neocene the land sank to a depth reaching 300 to 700 feet below present tide level and the Lafayette (Appomattox) formation was deposited. Still later in the Neocene the land rose 300 to 700 feet above present tide level, and the Lafayette formation was deeply and broadly trenched, fully half of its volume being degraded; and during the same high-level the basal plains of the Piedmont and Appalachian zones were trenched to depths of 150 to 300 feet. This high-level period was short in comparison with the early geologic periods, but long in comparison with the newer periods. With the beginning of the Pleistocene the land was again depressed to depths ranging from 50 to 700 feet below present tide level, and the Columbia formation was deposited. Subsequently the land rose to some hundred feet higher than its present altitude, and the submarine channels of the Hudson, the Delaware, the Susquehanna and the Potomac were excavated. From the history thus summarized three important conclusions flow: The first conclusion is that there have been two periods of considerable and rapid continental oscillation, the first Neocene or Lafayette, the second Pleistocene or Columbia; the second conclusion is that each period of submergence was comparatively short and immediately followed by a maximum high-level; the third conclusion is that the two oscillation-periods were remote and separated by a vast interval—measured by means of the erosion chronometer the Columbia period was 10 to 100 times as remote as the last glacial period, and the Lafayette period 100 to 1000 times as remote as the Columbia period.

STRIÆ AND SLICKENSIDES AT ALTON, ILL. By Prof. J. E. TODD, Tabor, Iowa.

[ABSTRACT.]

UNDER a stone culvert on Piasa street about 200 yards north of the round house of the Chicago & Alton railroad, at Alton, Ill., is an extended surface of limestone, beautifully planed, grooved and striated. It clearly presents features commonly ascribed to glacial action. The surface exposed has a breadth of nearly 50 feet, and is on three levels, the westernmost being a foot higher, and the eastern one two feet lower than the middle one which is twenty-seven feet in width. The direction of striæ and grooves is S 40°–45° W. (mag.) and some of the latter at least eight feet long.

About 150 yards southwest in apparently the exact direction of these striæ and upon the same level, other striæ are found having the same direction, except that they are on a curved surface twelve to fifteen feet wide, which without twisting or folding seems to rise regularly from an horizontal plane till it is at an angle of 30.° Much of it has been removed by quarrying, but traces of it extend to a height of twenty-five feet. The striæ are of the nature of slickensides, and samples of both the upper and lower rock were shown with the striated surfaces between.

Other cases were mentioned of slickenside surfaces observed. More particularly a very remarkable one found near the river a little below the Lime and Cement Works. Here is found a dyke-like mass of limestone protruding from the vertical face of the limestone in the quarry. The mass is about 40 feet high, 8 to 10 feet in breadth, and is left protruding about 20 feet from the wall back. Both sides of this mass are covered with horizontal striæ, no doubt of a slickenside character.

In conclusion it was urged that the first planed and striated surface was probably also a form of slickenside for the following reasons:

1. The planed surface was flanked on either hand and possibly in the rear with rounded summits of limestone rising twenty to thirty feet above said surface, and these limestone hills showed no trace of glacial action.

2. In front of said surface, as has been shown, the striæ from direction both vertical and horizontal, seem to pass into slickenside markings.

3. Abundant evidence had been found of a tremendous horizontal force acting in that locality adequate to produce the horizontal planation without calling in the aid of glaciers, whose action, on the other hand, it would be difficult to account for in this particular case.

4. The smoother polishing of the horizontal surfaces than of the oblique and vertical surfaces may be accounted for by their coinciding with planes of stratification.

5. Glacier striation and polishing is due to rock acting on rock. The same would be true in the case of slickensides.

SOURCE OF SUPPLY TO LATERAL AND MEDIAL GLACIAL MORAINES. By JOHN T. CAMPBELL, Rockville, Indiana.

[ABSTRACT.]

ATTEMPTS to account for the débris on glaciers where no mountain or hillsides are present from which the moraines can slide down upon the ice.

Assumes that moving glaciers conform to all the laws of fluid action, and that the under stratum of water in rivers at flood climb to the surface at every abrupt bend, and carry the sweepings up from the bottom, which

are thrown out into the stream in the form of "boils," where the sand, gravel, etc., sink in a river, but remain on the surface in a glacier.

The paper was illustrated with a crayon map.

THE EUREKA SHALE OF NORTHERN ARKANSAS. By T. C. HOPKINS, Geological Survey of Arkansas, Little Rock, Ark.

[ABSTRACT.]

THE Eureka shale, so named by the state geologist, from Eureka Springs, Arkansas, is an interesting formation by virtue of its position, occupying as it does the interval between the Silurian and the Carboniferous rocks in the Paleozoic area of northern Arkansas, or rather in that part of it lying north of the Boston Mountains.

It corresponds stratigraphically with the black shale of Tennessee, which Dr. Safford classifies as Devonian, but its correlation with formations elsewhere is now under investigation by Dr. H. S. Williams.

The shale varies in color, texture, and composition. The typical variety, which occurs over the greater part of the area, is a black, carbonaceous, pyritiferous alum shale forming a bed from two to fifty feet thick. In one locality a green calcareous shale from one to two feet thick overlies four feet of the black shale. In two localities it is accompanied by a soft yellow shale, while in other localities it occurs with sandstone and sandy shales.

In some localities the black shale is absent and in its place, in the Siluro-Carboniferous interval, are siliceous rocks, sometimes a sandstone, sometimes an arenaceous shale and sometimes a quartzose conglomerate. Black water-worn pebbles are quite numerous in the siliceous rocks and occasionally occur in the black shale, being more abundant where the rocks in the interval are comparatively thin—two feet and less. While the black shale has not been observed less than two feet thick, the siliceous rocks occur in many places but a few inches in thickness.

The shale is widely but unequally distributed over nearly the entire Paleozoic area of northern Arkansas. It is best developed in the western part of the area, and does not occur at all in the extreme eastern part, but is there replaced by sandstone or arenaceous shale. The most eastern point at which the typical black shale has been observed is on Cagen Creek twenty-five miles from the eastern border of the Paleozoic area. From Cagen Creek west for seventy miles exposures of this Siluro-Carboniferous interval show sometimes shale, sometimes sandstone, sometimes both. In the western part of the area, in the War Eagle Creek Valley, and the White River Valley from its confluence with the War Eagle to the Missouri line, there are prominent exposures of the typical shale, the maximum thickness of the bed being near the confluence of these two streams.

Fine exposures are reported by Mr. Siebenthal of the Geological Survey of Arkansas in the Illinois River Valley, further west.

Considering the fact that all the Devonian rocks and nearly all, possibly all, of the Upper Silurian rocks are wanting in this region, or are represented by only this comparatively thin bed of shale, one would expect to find great nonconformity between this shale and the underlying and overlying rocks. But in only two or three places has any nonconformity been seen, and at these points it was of such a nature and amount as often occurs within a single formation.

The absence of anything more than the suggestion of nonconformity between the Eureka shale and the rocks below it leads the state geologist to conclude that the interval between the deposition of the Lower Silurian and the Lower Carboniferous beds was marked by a depression which carried this area to a depth at which there was very little deposition of sediment during Upper Silurian and Devonian times.

PRELIMINARY REPORT OF OBSERVATIONS AT THE DEEP WELL AT WHEELING, W. VA. By WILLIAM HALLOCK, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

THE question as to the conditions which exist in the interior of the earth has always attracted much attention. The most important factor in the solution of this riddle is the determination or estimation of the temperatures there existing. The British Association has, for years, seized every opportunity to obtain data as to the rate at which the temperature increases as the earth's crust is penetrated. The most recent and reliable contributions on this subject are by Mr. E. Dunker of Halle, Germany, and were obtained from a 4170 foot well at Sperenberg not far from Berlin and a 5740 foot well at Schladabach near Leipzig.

These wells are both full of water, the circulation of which vitiates results or renders elaborate apparatus indispensable, and the thermometers must be protected from the pressure.

The Wheeling deep well, sunk by the Wheeling Development Co. and by them generously dedicated to science, is 4500 feet deep, 4⅞ inches diameter and *dry;* cased only to 1570 feet. The strata there are nearly *in situ*, undistorted and dipping only fifty feet to the mile. More satisfactory geological conditions can scarcely be imagined.

Being dry, ordinary U. S. Signal Service maximum thermometers were used and no especial precaution needed to be taken to prevent circulation of the air. The thermometers were lowered and raised, and depths measured by a steel wire.

Results:

TABLE I.

DEPTH FEET.	TEMP. FAHR.	DEPTH FEET.	TEMP. FAHR.
1350	68°.75	3125	88°.40
1591	70.15	3232	89.75
1592	70.25	3375	92.10
1745	71.70	3482	93.60
1835	72.80	3625	96.10
2125	76.25	3730	97.55
2236	77.40	3875	100.05
2375	79.20	3980	101.75
2486	80.50	4125	104.10
2625	82.20	4200	105.55
2740	83.65	4375	108.40
2875	85.45	4462	110.15
2990	86.60	———	———
		100	51°.30

These observations when plotted show a slow increase for the upper half of the uncased portion, about 1° Fh. for 80 to 90 feet, whereas the lower part shows a more rapid increase, about 1° Fh. for 60 feet. The whole series giving a well-defined and regular curve, with a slight deflection at 2900 to 3000 feet where an oil sand occurs. Practically all the rest of the uncased well is in shale. The increase in the rate at which the temperature rises as the bottom is approached can only be temporary or we should have an inconceivable or improbable state of temperature at comparatively slight depths.

The two distinct series of observations combined in Table I nowhere disagree more than 0°.3 Fh. and hence are very reliable and accurate.

Table II gives comparison of the results at the three great wells.

TABLE II.

NAME OF WELL AND LOCATION.	FEET FOR 1° FAHR.	TOTAL DEPTH.	TEMPERATURE AT TOP.	TEMPERATURE AT BOTTOM.
Sperenberg, near Berlin	59.2 ft.	4170 ft.	47°.8 Fahr.	118°.6 Fahr.
Schladabach near Leipzig	65.0	5740	51.9	135.5
Wheeling Development Co.		4500	51.3	110.3
Top and greatest depths	74.3	4500		
Mean of lower 3000 feet	75.4	4500		
Mean of above two	74.9	4500		

Inasmuch as the bottom of the well is some 3700 feet below sea level it seemed worth while to attempt barometer readings in it. The instruments used proved ill adapted to the work and the results were unsatisfactory.

Samples of air were taken at the bottom but could not be analyzed in time for publication here.

A series of observations in a coal mine near the well gave as a *very* probable value of the temperature of the top invariable stratum 51°.3 Fahr. From the mean annual temperature of Marietta and Steubenville as reduced by Schott it might be taken at 51°.5 Fahr.

Drilling is temporarily stopped, but we hope to go 5500 or 6000 feet. Mr. Anton Reyman, of the Development Co., has generously guaranteed half the expenses and we are waiting for a lucky man to furnish the other $3000 and enable the Wheeling well to be lifted from the second to the first place among the deep wells of the world.

The gratitude of the scientific world is due to the Wheeling Development Co. who ordered and paid for the well, to T. S. Kinsey who drilled it, and to Prof. I. C. White who discovered it and induced its owners to dedicate it to science.

Results of a well-boring at Rochester, N. Y. By Prof. Herman L. Fairchild, Rochester, N. Y.

[abstract.]

This boring shows the character and thickness of all the strata from the Niagara formation to the Archæan.

[This paper will be printed in Proceedings of the Rochester Academy of Science, Vol. I.]

On a deep preglacial river-bed near Akron, Ohio. By Prof. E. W. Claypole, Akron, Ohio.

[abstract.]

During the progress of some work near Akron, O., in 1890-1, there was occasion to sink a deep well to obtain brine, and the site selected was near the middle of a valley of preglacial date in which lay a considerable thickness of drift material of different kinds. Preparation was made to drive an eight-inch pipe through one hundred feet of this drift but rock was not reached until four hundred feet had been pierced. As this spot is within a mile or two of the present continental watershed it revealed a preglacial relief of the country far greater than had been previously supposed and at the same time a very great change of the preglacial drainage. Some of these effects, it is the purpose of this paper to trace.

THE RELATIONS OF THE ARCHEAN AND THE ALGONKIAN IN THE NORTHWEST. By C. R. VAN HISE, U. S. Geological Survey, Madison, Wisconsin.

[ABSTRACT.]

ONE class of geologists has maintained between the two an unconformity. Another class has maintained gradations, the whole being a series of sediments which have undergone downward increasing metamorphism. A third class has advocated the igneous intrusive character of a large part of what has usually been called Lower Laurentian.

In any given district the facts may support or appear to support any one of these conclusions, but the conclusion for this district cannot be carried over the whole region as has too often been done. In certain districts intrusive granite gneisses are prominent, but this does not demonstrate the absence of an earlier granite gneiss rock-complex upon which the Algonkian has been deposited.

Recently the so-called Huronian has been divided into two series. All are agreed that the upper of these series rests unconformably upon the Archean. Not so as to the lower series.

However, in the Marquette, Menominee and original Huronian districts the clearest evidence is at hand showing the lower Huronian to rest unconformably upon the basement complex. Localities illustrating this were described.

[This paper will be printed as part of a Bulletin of the United States Geological Survey.]

A FEW NOTES ON AN EXTINCT VOLCANO AT MONTREAL, CANADA. By HENRY LAMPARD, 102 Shuter St., Montreal, Can.

[ABSTRACT.]

THIS paper embraces a description of Mount Royal, Montreal, Canada; its geology and notes on minerals occurring in its various dikes; and other points of geological interest regarding it and some facts as to its probable age.

THE HIGHEST OLD SHORE LINE ON MACKINAC ISLAND. By F. B. TAYLOR, Fort Wayne, Ind.

[ABSTRACT.]

THE highest old shore line on Mackinac Island is at an elevation of about 205 feet above the present level of Lake Huron. The heavily drifted surface of the island above this level is conspicuous for the total absence of any evidence of post-glacial modification except by the ordinary subaërial agents.

The same statement applies with equal force to the relation of the heavily developed shore line, which extends along the Michigan shore at least as far south as Traverse City, to the drifted surface immediately above it. Below this great beach there is no unmodified surface, while above it, for 200 feet or more, there is no evidence of modification.

Beaches have been found at various higher levels, but they are all of a fragmentary character and are of comparatively weak development. The Algonquin beach so far as explored is very strong and continuous around Lakes Huron, Michigan and Superior. The same is true of the Iroquois beach in the Ontario basin, as described by Dr. G. K. Gilbert, Professor J. W. Spencer and others.

The character of the upper and lower series of shore lines suggests a broad classification, and probably a difference in the circumstances of their production. The lower Iroquois-Algonquin beach is strongly developed and continuous, while the beaches above these levels are weak and fragmentary. The comparative levels and similar differential elevation of Iroquois and Algonquin shore lines towards the north suggests that they form one continuous system and mark the margin of the same body of water. The upper fragmentary lines suggest temporary lakes of limited extent probably held by glacial dams.

THE STRUCTURE OF THE OUACHITA UPLIFT OF ARKANSAS. By LEON S. GRISWOLD, Dorchester, Mass.

[ABSTRACT.]

THE Ouachita uplift of Arkansas consists of a belt of closely folded Silurian strata lying between two broad belts of Lower Carboniferous rocks also much disturbed, the Silurian belt extending from Little Rock in a direction somewhat south of west into Indian Territory. The uplift seems to form a geological continuation of the Appalachian system. The movements, however, were relatively greater in the Arkansas area than they were east of the Mississippi, and the resulting folds were consequently sharper.

This paper was accompanied by a map of the area of the uplift and a diagram of the axes of the folds.

THE GEOLOGY OF NICARAGUA.[1] By J. CRAWFORD, Government Geologist of Nicaragua, Managua, Nic.

[ABSTRACT.]

GEOLOGICALLY considered, Nicaragua is divided from northwest to southeast into five zones, each of which differs from the others in many structural, lithological and mineralogical characters.

[1] This paper is condensed from several hundred pages of notes made by the author during the past three years of study of the natural history of Nicaragua.

The mean altitude of the land above the sea is nearly nine hundred feet, although no mountain or peak in the country exceeds 6700 feet in elevation.

The central currents of the trade winds pass over the northern part of Nicaragua and their direction is indicated by the rather irregular lines of concentric cones rising from beds of sand on some of the high mountain plains.

The soil on nearly every square league of its territory (about 50,000 square miles) is remarkably deep and fertile, and the climate, especially in the central mountainous zone and excepting the small southeastern corner, is delightful and has a nearly uniform temperature of about 65° F. in the central, and 82° F. in the western division.

THE FIRST DIVISION.

The first or central division extends in a northwest-southeast direction from about 83° 30′ W. and 11° 35′ N., to 85° 5′ W. and 14° 32′ N. This geographic division is made up of Laurentian, Taconic,[1] Cambrian and Silurian rocks in the form of granites, gneisses, sandstones, porphyries, slates, quartzites, limestones, and hornblendes. It contains also large deposits, of titanic iron ores, and much graphite; the acidic minerals, however, predominate.

The Laurentian rocks occupy the centre of the northern part of the division, while rocks of later age overlie them both on the east and west, while Mesozoic strata are deposited unconformably on the north side and extend northward to the Rios Patuca (emptying into the gulf of Mexico) and Choluteca (emptying into the gulf of Fonseca), these rivers being the geographical boundaries between Honduras and Nicaragua. The Archæan rocks were deeply folded and eroded before the Silurian rocks were laid down unconformably on them.

Devonian rocks rest unconformably upon the Silurian rocks. They consist of marls, coarse and gritty shales and red sandstones. The Devonian rocks in Nicaragua resemble those of Scotland more closely than they do those of New York.

Several large dykes of diorite, diabase and porphyries break through the rocks of the central division, the porphyries sometimes forming large bosses. Intersecting parts of this division are many fissures or lodes, frequently having walls of diabase or diorite, or one of these and slate, containing a gangue of quartz and several kinds of slates which have gold deposited in them and in their interstices, or they include veins and deposits of the ores of silver, tin, nickel, antimony, arsenic, etc. In a few places, platinum, iridium and osmium are found in creeks, mixed with the gangue of the mineral veins from which they have been removed by erosion and transported to the creeks by ice and water. Many of these mineral veins are quite rich in the precious metals.

Its mountain system is folded into anticlinal ridges. Several of these

[1]These rocks resemble more closely than any other that I have seen the Taconic rocks described by Professors Emmons and Marcou.

ridges have partly exposed anticlinal axes of granitic or syenitic rocks that now have an altitude of from 50 to 150 feet above the other parts of the mountain. A few of the peaks on these mountain ranges are the highest in Nicaragua, having an altitude of from 6500 to 6700 feet (aneroid barometer) above the Pacific Ocean. At several places on the mountains are areas of nearly flat tablelands, called "mesas," and having a superficial area of from nine to twenty square miles. These mesas are enclosed almost completely by peaks and ridges which rise from the edge of the mesa to from 100 to 500 feet above it and have nearly perpendicular exterior walls. Each of these mesas, so far as examined, has on its top a wide shallow valley covered with vegetation, excepting where small streams have eroded narrow, shallow channels into its granite or gneiss bed. At least three of these mesas have exposed in their valleys numerous, long, smooth, rounded masses of granite or gneiss. The longer axes of these bosses are parallel with the axes of the valleys. Many large, loose, flat rocks with striæ from 1½ to 2 inches deep are found in these valleys near their margins. In each of three, possibly more, of these elevated mountain plateaus is a cañon whose nearly perpendicular sides are from 225 to 1100 feet deep, measured from the surface of the valley on the mesa, and each cañon deepens for about three miles to the cliff-like walls of the mesa where it forms cascades. One of these cañons usually has no water in it, the others have streams from 16 to 20 feet wide and from 2 to 4 inches deep. The hydrographic area of neither one of these cañons and valleys exceeds fifty square miles, yet, at intervals, the almost perpendicular rocky walls of each cañon has been sculptured by erosion, from top to bottom, into figures of most grotesque appearance and having polished or smoothed surfaces. Some of these forms project two, three, or four feet into the cañon at right angles to the face of the walls, and many of them are several yards in length. The bed of one of the cañons after it emerges from the mesa and enters the valley between the lower foot-hills, is about 600 feet deep and the small creek in it turns about for more than a mile through a labyrinth of numerous upright, smooth, oval or rounded columns of rocks attached to the floor of the cañon. In another of these cañons the small creek flows over two falls, within 200 feet of each other, one 40 feet, the other 165 feet high, falling into large basins excavated in the rocks.[1]

Old volcanic fissures are still visible in this division, and there are also a few indistinct remnants of paleo-volcanic cones to be seen, but meteoric and glacial forces have, in a large part, decomposed and sorted the effusive rocks and reconsolidated their particles into sedimentary rocks, many of which have been metamorphosed. Dykes of porphyry are abundant, large

[1]From a mountain's peak near the cañon last referred to, the view over hundreds of mountains presents a scene of unmarred beauty. The tops of distant peaks are covered with remnants of sub-arctic vegetation, the ridges and mountain sides near at hand are clothed with tall, large exogenous trees, while the lower valleys are almost impenetrable forests of moss-covered trees interlaced by many kinds of large vines. The scenery is wild, attractive and lovely, but geological examination is slow and difficult.

and long, and in some places they have overflowed their walls or have been injected between rocks of other kinds. Some of the greenstone dykes are in a well preserved condition while other dykes have been extensively decomposed.

A few mineral springs, having temperatures of from 55° to 102° Centigrade, are found in this division and they invite more careful study. Their heat is not received from volcanic sources near at hand, for there are no post-lias volcanoes within about 150 miles of these hot springs.

The river system in this division usually originates in numerous and large mountain springs whose streams flow into the Caribbean Sea. The large amount of debris they have transported has until recently been spread over and deposited on the delta of all the rivers. During the past two years subsidence has ceased and elevation of that part of the Caribbean Sea coast commenced, and now the muddy streams flow far out into the sea.

Only a few fragments of fossils have been thus far discovered in this division. They are supposed to be *Eozoon canadense*, and impressions of species of Sphenothallus and Bythoptrephis, some Cyathophylloid and Halysitoid corals, and silicified exogenous woods.[1] Some of the limestones tell of fauna, and the graphite, of which there are several deposits, of the flora of Archæan and Primordial times.

THE SECOND DIVISION.

The second division is a narrow annex, on the east, to the division just described and extends to within about one hundred miles of the coast of the Caribbean Sea.

Its mountain system is monogenetic, the ranges of which have generally been eroded into isolated cones, short ridges and long valleys all from 1000 to 2800 feet above the sea.

There are two well-defined river systems, one including the dry beds of pre-Pleistocene rivers; the other, the present river channels. The former are from 100 to 500 or more yards wide and their dry channels are traceable for many miles to about the eastern limits of this division. In one instance, near and north of Rio Tungla (Princapulka) the old river is also to be found a few miles further east and extending into the western margin of the delta common to all the rivers both ancient and recent on this Caribbean coast north of the Rio Escondido (Bluefield). Six of the channels (three of old and three of recent rivers) unite at the eastern margin of the delta at about 84° 13′ west longitude and form three rivers: the Tungla (Princapulka), Matagalpa (Grande or Vul Vul), Escondido (Bluefield). There are small hills along all the old river channels in this

[1]These and many of the fossils mentioned in this paper were collected in Nicaragua for her exhibit at the Paris Exposition in 1889, and were, by order of the President and Government of Nicaragua, to have been transferred to the U. S. National Museum. Many of these objects can be replaced and efforts are now being made to replace them; but some of them, as a cranium and bones of man of much antiquity from a cavern in gneiss 300 feet below the earth's surface, cannot be replaced.

division; those near the old river north of Rio Tungla (Princapulka) consist of iron-clay slates and partly stratified fragments of chlorite and talcose slates, quartz, pebbles, sands and occasionally of clays interspersed with numerous small and a few large particles of gold. Fifteen miles north of the Indian village Wy-lo-was on the Rio Tungla (Princapulka) the old river channel and its valleys are very rich in gold placers. Another large placer, rich in gold, and appearing to be connected with glacial activities (it has the appearance of terminal moraines) is found in the bed and channel of a preglacial river, on the southeast side of and near the Rio Eas (or Yias), a southeastern confluent of the Rio Tooma.

The rocks of this second geographic division are of Carboniferous, Mesozoic and Cenozoic ages. Among the lower Carboniferous rocks are limestones; in the Permian are magnesian limestones, red sandstones and variegated shales; in the Laramie is brown coal; in the Cretaceous oolitic rocks and clays, gypsum and salt and slightly metamorphosed sandstones. All these rocks are generally covered unconformably by recent formations, usually soft excepting near dykes where they are metamorphosed The geological periods in this second division are separated, usually distinctly, by folded and eroded surfaces on which the succeeding strata are deposited. At several places Mountain limestone of the Lower Carboniferous forms the outcropping eastern margin of the rocks of this division.

Fossils.—But few fossils have been discovered, the examinations thus far made, necessarily being superficial or made in but few places. A few fragments of Sigillaria, Calamites and Lepidodendron have been found, besides those of Cycads, Conifers and ferns of Jurassic age.

Terminal moraines.—At several places in this geographic division are long groups of hills or ridges composed, so far as examined, of unsorted, generally unstratified deposits of clays and sands enclosing numerous stones and pebbles of various sizes, some rounded, others angular, some are smooth, others rough. These and a few probably glacially striated rocks in this division taken in connection with the deep cañons and the striated rocks in the adjoining division, just described, are evidently referable to a glacial epoch in Nicaragua, synchronous with that epoch in North America.

A few smoothed and polished surfaces have been found among the Permian rocks in localities where the planing and polishing could not have been done by the waters of existing streams, but no examination has been made that is sufficient to do more than arouse the suspicion that they may be indications of glaciation. These surfaces may have been caused by attrition with other rocks long since removed.

Numerous springs whose waters contain large percentages of matter in solution have been discovered in this uninhabited part of Nicaragua. The waters of these springs are cool, excepting in the case of one, which has a temperature of 120° F.

THE THIRD DIVISION.

The delta-shaped area of all the east flowing rivers forms the third division here treated. It has an area of over 15,000 square miles, or seven-

ty-five miles from west to east, and about 250 miles long from north to south, measured along the sea coast. The rich gold placers in Princapulka in the bed and valleys of preglacial rivers, extend to the western limit of this triangular area at about longitude 84° 25′ west, and latitude 13° 30′ north.

This part of the coast has subsided until within the past few years, at a rate equal to that of the sedimentation over the delta of the rivers Escondido (Bluefield), Matagalpa (Grande), Tungla (Princapulka), Wanta, Segoria (Wanx or Coco) and of several smaller streams. The hydrographic area of all these rivers is about 30,000 square miles. The elevation of the delta and sea bed appear to have recommenced during the past few years. The following evidences of elevation have been observed:

1. There are strips of alluvial deposits from a few feet to more than one hundred yards wide, along the margin of each river. The delta deposits were not removed although deeply covered by the unusually high floods in these rivers during 1889 and 1890. When these elevated lands, formed around the few trees growing in the delta, are removed, distinctly traceable flood marks made on those trees not many months ago are easily recognized.

2. Until the last few years corals grew nearly into the mouths of Rios Escondido, Matagalpa, Tungla, Wanta, etc. Now the tops of their branches are dead; also, the colored, sediment-loaded river waters that killed the corals, do not now, as formerly, deposit all their sediments in the delta, but their muddy waters are distinguished several miles seaward.

3. Atolls and barrier reefs off the coast of Nicaragua, extend at intervals nearly across the Caribbean Sea to 60° west longitude and mark the position of the submerged mountains which are connected with this division and were at one time elevated sufficiently to be a part of its land surface. Until recent years these corals had grown at a rate equalling the subsidence of the sea bottom; now, the peaks of their arborescent formations are exposed and dead above all ordinary tides and storm waves, while several feet below the low tide level innumerable Actinozoa now live.

THE FOURTH DIVISION.

The fourth division on the western side and adjoining the Archæan, Taconic, Silurian and Devonian rocks referred to in the first division, has for its western border the foot of the mountain ridges which extend to near the margin of Lakes Nicaragua and Managua;[1] the western border of this division extends from the lakes northwestward to about longitude 87° 10′, latitude 13° 15′.

Its systems of rocks appear to be of the same age as with those de-

[1]Lake Nicaragua is about 115 miles long and averages fifty miles wide; Lake Managua is about fifty-five miles long and averages twenty-four miles wide. It generally flows into Lake Nicaragua through Rio Tipetape, but often it has no outflow as its bed at the commencement of the channel Rio Tipetape is eighteen to twenty feet higher than the surface of Lake Nicaragua. At one time the ocean occupied the locality of these lakes and extended to the foot of the mountain ridges east of Lake Nicaragua. Most probably in Pleiocene times these lakes were separated by volcanic ejecta.

scribed in the second division, but differ in being much more extensively and completely metamorphosed.

Formations of the following ages occur in the second and fourth divisions:

Recent. Characterized by submerged forests, clay beds, peats, marls, volcanic tufas, stratified sands and ashes, and uncompacted volcanic ashes, lapilli.

Pleistocene. Characterized by terrace beaches and deposits, deeply eroded nearly perpendicular metamorphosed rock-walled gulches or cañons, erratic boulders, striated rocks, moraines, volcanic tuffs and agglomerates and alluvial conglomerates.

Pliocene or Sumpter. Characterized by lignites, loams and flinty shingles.

Miocene or Yorktown. Characterized by greenish marly limestones, reddish brown shelly sands in oblique layers and lignites.

Oligocene and Eocene. Characterized by limestones, clays, fresh-water marly limestones and sandstones.

Mesozoic. Characterized by oolitic flinty limestones, conglomerates and slates, bluish marly clays, greenish sandstones, pebbly sandstones, septaria, gypsum, salt beds, bituminous earths and marls.

Permian. Characterized by magnesian limestones, variegated shales, red sandstones, and lignites.

Carboniferous. Characterized by coal, mostly anthracite, sandstones and limestones.

The mountain system is monogenetic, and its ranges and ridges have been greatly folded, crushed and eroded. Several dikes intersect some of the mountain ridges and have overflowed in several places. The rocks in the western part of this division have been so much disarranged, metamorphosed and disintegrated as to render the structure difficult.

There are ancient volcanic fissures in this division, but the rocks filling them are rapidly disintegrating. They are not distinctly outlined in many places but partly covered with eruptions from more recent volcanoes. There is one line of old, rather indistinct volcanoes along the foot-hills on the west side of this division. These were active in Mesozoic times.

Several large springs, having a temperature from 70° to 100° Centigrade, flow from near the foot of the mountains in the northwestern part of this division; they usually contain large percentages of alkalies.

Fossils. In a crescent, formed by the Rio Viejo, in the valley Sebaco, are many tons of the separated, disarranged and silicified bones of reptiles and other vertebrate animals. They appear to be of Mesozoic and early Cenozoic types.[1]

These bones are buried 30 to 100 feet deep in partly hardened sands held in position by a nearly horizontal stratum three to four inches thick of cemented fine sands. About fifteen miles distant on the other side of this valley of silicified bones, at the foot of the mountains, are many small

[1] Many specimens of these bones were sent in 1889 to the exposition in Paris, but as already stated, were not classified and have been lost.

hills having long ridge-like extensions toward the entombed bones, composed, so far as examined, of sands, clays, boulders, large and small fragments of rocks, some striated, rough and smooth-edged pebbles all mixed irregularly, excepting in a few places where stratification is evident. The locality of this valley of bones is such, that, admitting great elevation and a glacial epoch, evidences of which are almost unquestionable, the mammals and reptiles could not have migrated northward or eastward because of the cold, nor could they have escaped southward or westward because of the volcanic lavas and the ocean.

This division is very interesting and wonderfully varied in its stratification, lithology, mineralogy, botany and mineral springs.

THE FIFTH DIVISION.

The fifth division embraces the northwestern and southwestern parts of Nicaragua, including the two large lakes Xolotan (or Managua) and Nicaragua which were once part of the Cenozoic ocean, also including several small lakes in the craters of volcanic cones. These cones were formed at various periods corresponding with Oligocene or Vicksburg, Miocene and Pleiocene. Some of these crater-lakes contain nearly pure or only slightly alkaline waters, as Masaya, Apoyo, Tiscape, etc.; others contain large amounts of sulphur and alkalies, as Nejapa (which gives iodine reactions and possesses in a remarkable degree the property of preserving and strengthening animal membrane, tissues, etc.), Asososca, etc.

This division may be geologically subdivided into two areas.

The first subdivision is connected with and extends southwest from the northwestern part of the first division to near the Gulf of Fonseca. Its rocks are paleozoic. It is intersected by many lodes, generally striking N. E. and S. W., and containing gold as the principal metal, but those passing into granitic rocks or between granitic and gneissic rocks and shales have as their principal metal silver, tin or manganese. The gangue of all these metal-bearing veins is quartz and magnesian slates, and their walls are granite or gneiss, or one of these on one side and shales on the other, excepting a few of the gold-bearing veins which have walls of diabase or diorite. Some of the most valuable metaliferous veins in the southern part of this subdivision have been frequently and largely faulted and otherwise disturbed.

Silurian and Devonian rocks extend from the Rio Chomteca southward, in the disputed territory between Nicaragua and Honduras, to the Rio Negro and are succeeded by coal measures of the Acadian part of the Dyas (Triassic) and limestones, marls and auriferous slates of the Jurassic period, and these, by lignites of the Laramie (Upper Cretaceous) as far south as a tide water estuary named Estera Real, covered in the southern part, by alluvial and estuarian formations, gypsum, salines, and marls, of Cenozoic age, but more especially of the Pleistocene.

Much geological interest centres in the southern part of this subdivision especially on account of the ejectamenta from Mesozoic and Cenozoic volcanoes which are often found interbedded with sedimentary strata,

thus forming reliable records of the epochs of principal eruptions from each of the two neighboring volcanic cones, Cosigüina and Viejo.

The second subdivison of the fifth division includes the western and southwestern parts of Nicaragua, embracing all the lakes referred to in the introduction to this division, and extending from the Pacific Ocean eastward to the western foot-hills mentioned in the fourth division as being west from the Amerique range of mountains. All of this subdivision, with the exception of a few low hills to be described hereafter, is composed, to great depths, of later volcanic eruption from the one line of volcanic fissures and cones which pass through or appear above it, northwest and southeast: the principal ones composing this line beginning at the northwest are Cosigüina, Viejo, Telica (now emitting hot light-grey columns of aqueous vapors), La Pilas Mometomba (now emitting rather darkly colored columns of aqueous vapors), Mometombito, Masaya, Mombucho, Zapatero, Ometepa (smoking) and Madera which is the most southeasterly.

On this erupted mass are situated all the large towns in Nicaragua, excepting Matanalpa and Jenotega in the first division, and more than seven-tenths of the population of the country reside in the towns, cities, fertile valleys and mountain sides in this subdivision.[1]

All post oligocene volcanoes in Nicaragua are on a line in this subdivision. They have been named above, are nearly equidistant from each other, and appear to have been and possibly are now connected with each other by a deep-seated fissure extending about 200 miles N. W. and S. E. across this subdivision.

The southern parts of first, third and fourth divisions are covered deeply by volcanic tufas, in laminæ $1\frac{1}{4}$ to 3 inches thick and forming beds from 20 to 150 feet thick. Terraced beaches are also found in the southern part of these four divisions.

In several places in this subdivision the darker and more easily melted minerals, basalt, dolorite, andesite, and black scoriæ, have been transported by water to greater distances from the volcanic cones than the lighter colored and more acid minerals, pumice, obsidian, trachyte, light-colored scoriæ, and rhyolite, as if the heavier basic ejecta was the last erupted and the first to be removed by water. On the sides of some deep fissures in volcanic formed masses in this subdivision deposits of acid and basic ejecta can be seen with sufficient distinctness to indicate the time of greater and less energy in the volcanic activities, also places where the heavier materials overlie the lighter ones.

Fossils. Many silicified bones of Cenozoic and Pleistocene animals similar to Elephas, Mylodon, Glyptodon, Mastodon, Cervus, Ursus and others

[1]In the valleys grow to perfection, sugar cane, cacao, plantains, bananas, tea, corn, and many fibrous plants, as Agaves, Linums, etc., also, many valuable trees, as, Mora tinctora, Siphonia elastica, Cedron nicaraguensis, Tamarinda, Mangoes, Sapote, Citrus, etc., also, coffee of unsurpassed aroma is produced at altitudes of 2000 to 4500 feet above the sea. on the sides of volcanic masses in this subdivision. The valleys of Chenandega, Possittega, Palacio, Mirate, Tangue and Cosegüina are remarkable for the excellence of the above-named and similar agricultural productions, semi-tropical fruits and grasses.

are embedded in the volcanic materials in the region between the Pacific and Lake Nicaragua. These bones are so scattered, however, that it seems to be impossible to reconstruct a single complete skeleton.

Footprints. Thousands of footprints of man and several animals are found deeply impressed on a sedimentary stratum of conglomerate composed of volcanic ejecta of different periods of eruption and from different depths and through different fissures and cones on the southwest side of Lake Managua. This stratum, at its least depth near the lake, is fourteen feet below the surface and gets to be several hundred feet deep to the south and southwest; above it are several other volcanic strata some of which are three and a half feet thick. The fact that these footprints are now deeply covered by several strata of similar, partly hardened conglomerates, and the comparison of the volcanic ejecta near this valley with the volcanic history of the region in the southern part of the first subdivision of the fifth division and a comparison with the lavas and strata of materials ejected by volcanoes in other countries, lead to the belief that the human footprints were made during part of the Champlain epoch by men who were then congregated in large numbers near the southern shore of Lake Managua.

The following are the general conclusions reached concerning the geology of Nicaragua:

I. Nicaragua has a central Archæan cone upon which the later rocks have been laid down unconformably, the different rock systems usually being separated by nonconformities.

II. There was a glacial epoch in Nicaragua synchronous with the glacial epoch in North America, during which time the land area extended more than fifteen hundred miles further east than at present. At the same time there was great volcanic activity in the region then elevated to the southwest.

III. The eastern coast of Nicaragua ceased to subside a few years ago and it is now apparently being slowly elevated.

THE PENINSULA AND VOLCANO OF COSIGÜINA. By J. CRAWFORD, Government Geologist of Nicaragua, Managua, Nic.

[ABSTRACT.]

WITH the exception of a line of low ridges on the west the peninsula of Cosigüina is a volcanic extension of the territory of Nicaragua northwestward into the Pacific ocean. It lies between longitudes 87° 18′ and 87° 35′ west and latitudes 12° 35′ and 13° 09′ north, having an average length of about forty miles and a width of about twenty-eight miles. The Pacific ocean washes its western and southwestern sides, while the gulf of Fonseca washes it on the north.

The Cerro Cosigüina originated during the Laramie, or, possibly the Lias, as a submarine volcano. It has an altitude of from 2000 to 2850

feet above the Pacific ocean, or, including its volcanic cone, 3280 feet, and extends from the northeast terminus of the peninsula, southeastward, along and near the western margin of the gulf of Fonseca, having a total length of about fifteen miles. From a few leagues distant at sea it looks like an immense oblong pyramid, marking the southwest side of the entrance to the gulf. In 1835, 1828, 1808 and earlier, Cosigüina and Conciagua, which is several leagues away on the north side of the gulf of Fonseca, were visible for many leagues at sea, emitting dimly glowing lurid reflections from clouds of dust that hung around and above their intensely heated crests. Sometimes dark columns of materials were ejected several thousand feet above the trembling apices of their cones, while the volcanic dust was carried by currents of air several hundred miles.[1]

The sides of Cerro Cosigüina have been deeply eroded and the ridges thus formed on its sides, excepting those near the central volcanic cone, are covered with a heavy and vigorous vegetation which includes several varieties of slow-growing exogenous trees like the oaks.

Near the middle of the longitudinal axis of this cerro, and from its highest plateau, rises the volcanic cone of Cosigüina, to an altitude of 430 feet above the mass of the cerro and 3280 feet above the level of the Pacific ocean. The crater, which is now partly filled with water, is about 1000 feet wide, and 2400 feet deep to the surface of the lake. The depth of this lake is not known for it is inaccessible because of the steep inner wall of the crater, which is composed of partly compacted lapilli, sands and ashes, from which project here and there masses of hard lava and porous sulphur. On the northwest side a narrow fissure extends from the lake to the top of the crater.

Commencing on the west side of the cerro, just northwest of the base of the volcanic cone, a ridge 800 feet high at its union with the cerro, extends for about fourteen miles southward, gradually declining to an altitude of 150 feet at its terminus at the ocean. Above its junction with the cerro are several spurs projecting at different intervals until within two hundred feet of the summit of the mountain, and these spurs mark, like beach lines or terraces, the former height of ejectamenta from the volcano all over the peninsula, and, in part, indicate the immense amount of materials eroded from this small peninsula.

On the east side of the cerro, nearly opposite the long ridge just referred to, and adjoining the volcanic cone on the northeast, is a narrow, deep fissure penetrating to within a few hundred feet of the vertical axis of the volcano. Its bed is about three hundred feet above the gulf of Fonseca, it is from twelve to twenty feet wide, and its walls are formed of loose fragments of lavas, basalts and black scoriæ. The walls are nearly perpendicular with numerous fragments of lava overhanging or projecting into the cavity and so darkening the irregular and dangerous passage as to require artificial light to guide an explorer to where it seems to end,

[1]Captain Eden of the British Navy reports sailing during an eruption through floating pumice stones from these volcanoes, when eleven hundred miles distant.

1700 feet below the summit of the cerro. At the inner end this passage expands into a cavern about 60 feet long, lined with projecting sharp-edged trachytes, andesites, rhyolites and stony and vesicular lavas; no glassy forms of eruptive rocks were found in this cavern, and no basic ejectamenta in the bed of the fissure excepting a few pieces which had fallen from the top, several hundred feet above.

Many wide ravines, perpendicular to its longitudinal axis, and deepening as they descend to the valley, have been excavated from the crest to the base of the mountain exposing hard agglomerates, traps, and vesicular and sandy lavas. Between these ravines the surface is covered with vigorous vegetation. All of the trees within three or four miles of the central cone have grown to their present size, from 6 to 26 inches in diameter, since the eruption which took place in 1835.

A disconnected chain of hills from 750 to 1200 feet high, elevated by lateral, submarine pressure, acting from the direction of the atolls and barrier reefs lying to the southwest, extends for about thirty-five miles southeastwardly, within four miles of the Pacific ocean. Each link of this chain of hills is from two to five miles long and curved, having its convex side fronting to the southwest.

Several large valleys extend from the volcanic cerro, widening rapidly toward the ocean. They rest upon a floor of steep, trap-like lava, the upper surface of which is exposed at low tide on the shore of the ocean and in the gulf. In these valleys are numerous knolls or hills from 100 to 850 feet higher than the valleys. These hills are remnants that have more successfully resisted erosion.

Several cañons, from 20 to 50 feet wide on their bed and from 150 to 200 feet deep where they terminate, cross the valleys from the foot of ravines in the sides of the mountain to either the gulf or the ocean, and along their precipitous sides distinctly display the number of eruptions and the character of the ejectamenta of the volcano from its last submarine to the last subaërial eruption in 1835.

Fissures appear at many places near the foot of the cerro and at a few places, from two to six leagues distant, in the valleys. From these fissures issue large streams of water having a temperature of from 45° to 75° Centigrade, and containing large percentages of sulphur and alkaline salts. These large, swift currents of hot water, from 20 to 60 feet wide and from 2 to 4 feet deep, soon penetrate the loose, sandy soil and disappear.[1]

The mountain and peninsula of Cosigüina originated as submarine volcanoes which began earlier than the Eocene, but which were more active during the later Eocene or earlier Oligocene periods, and are most probably synchronous with the limestones of the Upper Claiborne and of the Lower Vicksburg group. The submarine lavas, in both the Pacific ocean and

[1]More than ten thousand head of cattle and many wild partridges, turkeys, deer (*Cervus nicaraguensiana*) range in the evergreen forests on this part of the peninsula. They, and the few Indians living in the locality have no other kind of water to drink than these tepid and highly impregnated mineral waters, yet the animals are comparatively large and well conditioned.

gulf of Fonseca, on which the mountain and peninsula rest, are easily distinguishable from any of the later subaërial flows. They descend rapidly into the Pacific ocean basin just off the coast, but on their eastern side, across the gulf of Fonseca, they alternate with sedimentary strata of Laramie age, and in a few places with earlier, possibly Lias rocks. They are interbedded with fluvo-marine deposits, gypsiferous marls, etc., and with limestones of both the Vicksburg and Claiborne groups of the Eocene. They also alternate with and are mixed with coal of Upper Cretaceous age. To the northeast for many leagues knolls and hills of metamorphic rocks, probably of Cretacéous age, are mingled with these lavas. Some of the upper beds in these hills, however, are of recent eruptive origin.

The rocks at the extreme end of the fissure which enters the volcanic cone on the east side are andesites, trachytes and acid lavas. Several hundred feet nearer the surface are large boulders of granitic rocks and breccia conglomerates made up of fragments of andesites, trachytes and trap rocks cemented by sands, ashes, etc., also dolorites apparently in fissures or lines parallel with the longitudinal axis of the mountain. Near and at the surface most of the rocks are dolorites, dark or black basalts, dark vesicular and black scoriaceous lavas, lapilli and other basic sands and ashes. These basic rocks are strewn thickly over the surface of the valleys to a distance of four or five leagues from the volcano.

About a thousand feet below the crest of the crater on its southwest side, is an oblong, sharp-edge mass of granitic rock measuring 6x7x9 feet, resting on a surface of lava. None of its near geological relations are to be seen south within several hundred feet. It was erupted through the crater probably towards the latter part of the most active life of the volcano, but at a time when the forces were so weak as not to throw it far, and it fell in a bed of fresh ashes which have since been washed away.

The valleys and their enclosed hills are composed of fragments of granite, volcanic rocks, lapilli, sands and ashes, on which are thickly strewn, reddish basalts, reddish vesicular lavas, black basalt and scoriæ, the latter two having a dull appearance.

The precipitous sides of the cañons (100 to 250 feet deep) in these valleys are marked by, and in part record fourteen deposits of different kinds and colors, ejectamenta giving evidence of at least that number of periods of volcanic activity from the last submarine to the latest subaërial explosive eruptions. Numerous evidences of deep denudation and subsequent filling up are observable at several places on the sides of these deep cañons recording seasons of volcanic activities followed by great floods of rain.

The waves of the Pacific ocean are rapidly removing the peninsula and depositing the sediments in the off-shore basin in the crescent shaped western coast of Nicaragua. Sediments of decomposed volcanic rocks have, during two or more geological epochs, been washed out to and deposited in this basin, from Salvador, from Honduras and from Nicaragua, until this deposit has attained great depths, probably 20,000 to 30,000 feet. This deep sediment appears, in some way, to decrease the activity of the vol-

canoes in Nicaragua, and of those at about the same distance in Salvador and Honduras.

The water in lake Cosigüina, deep down in the crater, is not all from the small hydrographic area above it; such a supply would be exhausted in a few months by evaporation. Its water is probably the head of the numerous hot (46°–76° C.) fountains which rush from fissures opening in the valleys at and near the foot of the mountain. The surface of this lake is 300 feet above the valley. Its conditions invite more careful investigation.

Volcano Cosigüina is on a line of volcannic cones of which the other cones on this line are, in order, N. W. and S. E., as follows: Viejo, Telica, Las Pelas, Asosasca, Mometombo, Mometombito, Masaya, Mombacha, Zapatera, Ometepa and Madera. These are the only postmiocene subaërial volcanoes in Nicaragua, and they appear to have been united to each other by, and in part supplied with, materials from a deep seated subterranean fissure, this fissure connecting across Nicaragua for more than two hundred miles the large volcanic group in Salvador with the equally numerous and extensive group of volcanoes in Costa Rica. The volcanic line in Nicaragua originated below the Eocene ocean and the ejectamenta form nearly all the western part of the country, where seven-tenths of its population reside, and on which its largest towns are built, viz.: Chinandega, Leon, Managua, Masaya, Granada and Rivas. Much information regarding the history of the eruption may be had by a study of the materials that have been intruded into and alternate with the sedimentary strata several miles northeast and east from Cosigüina and north of volcano Viejo.

Cosigüina and several of the volcanoes above named were active, almost continuously, during Pleistocene times. At present vapors often rise from or form caps of clouds on the cones of Ometepa, Momatomba, Telica, and occasionally on Cosigüina. Since the commencement of the rainy season in June last, columns of aqueous vapors are ascending from Ometepa, Momatomba and Telica occasioned by an increased supply of water from the almost continuous rains, and not from an increase of heat in the volcanoes.

PROCESSES OF MOUNTAIN-BUILDING AND THEIR RELATIONSHIP TO THE EARTH'S CONTRACTION. By WARREN UPHAM, U. S. Geological Survey, Somerville, Mass.

[ABSTRACT.]

SIX classes of mountain ranges are discriminated, which, from predominant features of their structure, are named as (1) folded; (2) arched; (3) domed; (4) tilted; (5) erupted; and (6) eroded.

1. *Folded mountain ranges.*—Foremost in their geographic importance, the most prolonged mountain belts consist of folded rock formations. The strata forming the upper part of the earth's crust are bent up and down in

long, nearly straight or curving, wave-like ridges and troughs, and where their disturbance was greatest the successive ridged folds are closely pressed together and are often driven forward into an inclined position, the lower side of the fold being inverted. This type is represented by the Appalachian, Atlantic and Laurentian mountain systems, for which collectively the name Appalachian-Laurentide belt is proposed. In the Old World it is more grandly exemplified by the Alp-Himalayan belt, reaching from the Atlas and Pyrenees to the China sea. In the Andes-Cordilleran belt of South and North America, a long and eventful history of extended plication and upheavals in many separated geologic epochs is more or less clearly revealed; but the latest accidents befalling this belt during the Quaternary era require special notice under the fourth structural type.

2. *Arched mountain ranges.*—Far less frequent than the foregoing, and indeed known only in parts of the Cordilleran belt of the western United States, is the arched structure, represented by the Uinta range and the Junction and Yampa mountains, well described by Powell and White. In the Uinta range a great thickness of many rock formations has been raised in an arch about 150 miles long from east to west and thirty to forty miles wide. The upheaval took place during the Tertiary era, mostly in its earlier portion, and the whole extent of the upward arching was about five and a half miles, reduced by erosion to an altitude of 13,000 feet. Upon each side of the Uinta arch and about its ends, the stratification is steeply inclined and occasionally cut by faults; but higher up the inclination diminishes and the strata extend across the top as a flattened dome, without folding or dislocation.

How were the mountain-building forces applied to form this arch? Its short extent in proportion to its width, and the absence of plication, make it difficult or impossible to refer it to lateral pressure, which has been regarded as the manner of application of the energy forming the great folded ranges. All the features of the Uinta range instead point to upward pressure as the form of mountain-building energy to which its elevation was due. It is very important, however, to note that the process of the Uinta elevation was so gradual and slow that the rivers which flowed across the area before its upheaval were not turned aside, being able to cut down their channels, which in the heart of the mountains are precipitous, narrow cañons, as fast as the elevation progressed.

3. *Domed mountains.*—The structural type here designated is exemplified by the Henry mountains in southern Utah, which have been elaborately studied by Gilbert. These mountains were formed as dome-shaped uplifts of previously horizontal formations, by the volcanic injection of immense lenticular masses of porphyritic trachyte between the strata. The injected lava mass is named by Gilbert a laccolite (cistern stone). The uplifting of the Henry mountains was contemporaneous with the growth of the Uinta range; but the former was sudden, the effect of each laccolite intrusion being completed at once, while the latter was a very gradual upheaval. The two cannot be referred to the same means of elevation, though their more remote causes were doubtless nearly related or identical.

4. *Tilted mountain ranges.*—The Wahsatch mountains and Sierra Nevada are examples of tilted mountain ranges. The Wahsatch range has been elevated along fault lines which form its western boundary, adjacent to the area of Lake Bonneville and the present Great Salt Lake. It is an immense mountain mass which has been tilted by upheaval of its western border and sinking of its eastern portion. The Sierra Nevada, on the other hand, has been upheaved along fault lines bounding it on the east, and is concisely described as principally a single great block of the earth's crust, about 300 miles long from north-northwest to south-southeast and fifty to seventy miles wide, tilted by elevation of its east side and depression of its west side. Between these grand mountain ranges which look toward each other on the east and west limits of the Great Basin, many minor ranges occur, trending from north to south, all of which have the same structure and origin through faulting and tilting, so that this is called by Powell the Basin type of mountain structure.

Many stages of mountain-building have left their impress on the great Cordilleran belt of the western part of the United States and the Dominion of Canada. The Gold and Selkirk ranges of British Columbia, according to Dr. George M. Dawson, consist of Archæan, Cambrian, and Silurian formations, which were pushed up into mountain folds before the close of these very ancient divisions of geologic time. The auriferous slates of the Sierra Nevada, as Becker has shown, were similarly built up in a folded mountain range at the close of the Gault epoch in the Cretaceous period. During the ensuing long lapse of time to the end of the Tertiary era, this precursor of the Sierra Nevada range had been worn down to only a moderate elevation; but the beginning of the Quaternary era, according to LeConte and Diller, brought revolutionary changes. The previously base-levelled region which now forms the Great Basin was then upheaved as a high plateau; intense volcanic activity was manifested in many parts of this area, and especially from the vicinity of Lassen Peak and Mt. Shasta northward to the Columbia river and eastward along the Snake river to the Yellowstone National Park; and long faults, running mostly from north to south, divided the distended region into a multitude of orographic blocks, which, being soon allowed to sink, became tilted in their subsidence and form the present Basin ranges.

Extending our view to embrace the entire belt of which the Rocky mountains, Sierra Nevada and Coast range are parts in the United States, we see that it forms the western side of both South and North America. Its length from Cape Horn to Alaska is about 10,000 miles of a great circle, from which the irregular course of the chain is nowhere widely distant. In Bolivia and Peru the highest portions of the Andes are found by David Forbes to be folded Silurian strata, which are so associated with Devonian, Carboniferous and Permian formations, as to imply that the principal epoch of mountain plication there, as of the Appalachian system, was at or near the close of the Palæozoic era. But later epochs of plication are also recognized in portions of the Andes, as likewise in the rocks of the Sierra Nevada, the Wahsatch and the Coast range in the western United States. Indeed, the last-named range, and the range which cul-

minates in Mt. St. Elias, the former stated by Whitney and Turner to contain infolded Pliocene beds, and the latter found by Russell to consist of faulted and tilted masses of Pliocene or early Quaternary and older rocks, were formed by very late mountain-building, perhaps correlative, like the faulting and tilting of the Basin ranges, with great movements of the earth's crust producing and accompanying glaciation. The present height of the Andes and Cordilleran ranges, and also of the Appalachian, Atlantic and Laurentian mountain systems, must be ascribed to Tertiary and Quaternary upheavals of these belts, portions of which had long before and at different times been folded and raised to mountain heights, but afterward had suffered erosion almost or quite to a base-level.

5. *Erupted mountain ranges.*—Volcanic action has often been developed on a grand scale along the deep fissures and fault-planes which border and intersect tilted mountains and plateaus, as notably in the Andes and in Mexico, where it has built up very conspicuous volcanic cones of outpoured lavas and ejected blocks, bombs, lapilli and ashes. Often, too, prolonged fissures, which may intersect each other (as in the Hawaiian islands), reach down through the earth's crust to lavas that well up and build mountain masses and plateaus, while the crust segments have been only slightly tilted and sometimes lie wholly beneath the sea level. Such eruptions form the Cascade range, the mountainous plateaus of Iceland and the much eroded Färöe islands, the Deccan plateau in India, the volcanic chains of the Sunda, Kurile and Aleutian islands, and the Hawaiian, island belt. The Cascade range is a typical example of this class, having an extent of more than 500 miles from south to north across Oregon and Washington, showing a thickness of nearly 4,000 feet of lava where it is cut through by the Columbia, and bearing here and there volcanic peaks which rise to altitudes 10,000 to 14,000 feet above the sea.

6. *Eroded mountain ranges.*—Besides the preceding types of orogenic upheavals, there have been broader uplifts of the whole or large parts of continents, which Gilbert and White have called epirogenic movements. The sixth class of mountains is distinguished by not having an origin from any definite mountain-building process, being simply remnants of extensive areas which have been uplifted by epirogenic energy as great plains and since have been deeply eroded. The plains which slowly rise from the Mississippi valley and Manitoba westward to the foot of the Rocky mountains afford examples of this type of mountain structure. Perhaps the most striking is the range of the Crazy mountains in Montana, which lies immediately north of the Yellowstone river near Livingston and is conspicuously seen from the Northern Pacific railroad. These mountains trend slightly west of north, and extend about forty miles with a width of fifteen miles, attaining an elevation of 11,178 feet above the sea and 5,000 to 6,000 feet above the prairies at their base. Their structure has been thoroughly studied by Wolff, who finds that they consist of late Cretaceous strata, soft sandstones, nearly horizontal in stratification, intersected by a network of eruptive dikes. The more enduring igneous rocks have preserved this range, while an average denudation of not less than one mile

in vertical amount reduced all the surrounding country to a base-level of erosion. The Highwood mountains, about twenty-five miles east of Great Falls, Montana, having a height of 7,600 feet above the sea or about 3,500 feet above their base, are described by Davis as displaying the same structure and therefore similarly testifying of great denudation.

Reviewing this classification of mountain ranges for the purpose of discovering what elements of diversity and of unity characterize the manifestations of mountain-building energy, we see this to be of two kinds, the second being presented under four phases. The first kind of mountain-building energy, producing folds, is evidently lateral pressure, and is ascribed by geologists and physicists to the contraction of the earth's mass by its secular cooling, with resulting adaptation of the rigid outer part of the crust to the shrinking interior. The second is energy acting vertically upward, which has produced the four other types of constructive mountain ranges and masses by diverse phases of its manifestation, namely, the slow arching of limited areas, as the Uinta, Junction and Yampa mountains; the sudden volcanic lifting of the laccolite mountains; the upheaval and subsidence, with faulting and tilting, of the Basin ranges; and the outpouring of lavas, as in the Cascade range. Each of these four phases of vertically acting energy depends upon a viscous and plastic, neither solid nor perfectly liquid, condition of the earth's interior. Greater pressure of some portions of the crust than of others upon the plastic interior would induce each phase of the upward energy in mountain-building. Where isolated blocks of the crust yielded slowly to the resulting quasi-hydrostatic pressure of the interior, mountains of the Uinta type were formed; but large areas, as the Great Basin, being swelled upward and anon subsiding, as the interior pressure increased and diminished, have become marked by tilted mountain ranges. Where portions of the interior, often of great extent, have become liquid lava, its extravasation by the same pressure has formed laccolite mountains and erupted mountain masses.

These two kinds of mountain-building energy appear to be both caused by the earth's contraction in cooling; and the second or upwardly acting kind of energy is closely dependent on the first in the intermittent and occasional relief of stress of the earth's crust by its folding along the great orographic belts. Between the epochs of mountain-building by plication, the diminution of the earth's mass produces epirogenic distortion of the crust, by the elevation of certain large areas and the depression of others, with resulting inequalities of pressure upon different portions of the interior; and these effects have been greatest immediately before relief has been given by the formation of folded mountain ranges. Two epochs have been preëminently distinguished by extensive mountain-plication, one occurring at the close of the Palæozoic era, and the other progressing through the Tertiary and culminating at the beginning of the Quaternary era, introducing the Ice age. During the last, besides plication of the Coast range, of the Alps, and the Himalayas, a very extraordinary development of tilted mountain ranges, and outpouring of lavas on

an almost unprecedented scale, have taken place in the Great Basin and the region crossed by the Snake and Columbia rivers. With the culminations of both of these great epochs of mountain-building, so widely separated by the Mesozoic and Tertiary eras, glaciation has been remarkably associated, and indeed the ice accumulation appears to have been caused by the epirogenic and orogenic uplifts of continental plateaus and mountain ranges. Since the disturbances, with glaciation, closing Palæozoic time, the same combination of events has not recurred until the Quaternary era, which is not only exceptional in its accumulation of ice-sheets, but also in its numerous and widely extended movements of elevation and subsidence, and in its mountain-building and renewed upheavals of formally base-levelled mountain belts. The earth's surface is probably now more diversified by the existence of many lofty mountain ranges than has been its average condition during the previous long eras of geologic history.

[This paper is abridged from an address before the Appalachian Mountain Club, April 8, 1891. It is published in full in Appalachia, vol. VI, and in the Popular Science Monthly, vol. XXXIX.]

A NEW LOCALITY FOR METEORIC IRON WITH A PRELIMINARY NOTICE OF THE DISCOVERY OF DIAMONDS IN THE IRON. By Dr. A. E. FOOTE, Philadelphia, Pa.

Historical sketch of the discovery.—In the latter part of March, 1891, the mining firm of N. B. Booth & Co., of Albuquerque, New Mexico, received a letter from a prospector in Arizona informing them he had found a vein of metallic iron near Cañon Diablo, sending them at the same time a piece with the request for an assay. Some time in April this piece was examined by a Colorado assayer who reported "76.8 per cent of iron, 1.8 per cent lead, ½ oz. silver, and a trace of gold. From its appearance we should take it to be a furnace product."[1]

This result was naturally not satisfactory to the mining firm and a mass weighing forty pounds was broken into several fragments with a trip hammer. One of these was sent to the President of the Sante Fé Railroad, and another to Gen. Williamson, the land commissioner of the Atlantic and Pacific Railroad Co., in Chicago. Gen. Williamson consulted me as to the probable value of the so-called mine of "pure metallic iron," stating on the authority of the prospector that the vein had been traced for a distance of about two miles, that it was forty yards wide in places, finally disappearing into a mountain and that a carload could be taken from the surface and shipped with but little trouble.

A glance at the peculiar pitted appearance of the surface and the remarkable crystalline structure of the fractured portion convinced me that

[1]This assay was of such a remarkable character that I took the trouble to stop at the city where it was made and ask how such extraordinary results were obtained. I was informed that the lead, silver and gold were probably the results of the materials used in making the assay.

the fragment was part of a meteoric mass, and that the stories of the immense quantity were such as usually accompany the discovery of so-called native iron mines or even meteoric stones. As soon as possible in June, I made a visit to the locality and found that the quantity had, as usual, been greatly exaggerated.

There were some remarkable mineralogical and geological features which together with the character of the iron itself, would allow of a good deal of self-deception in a man who wanted to sell a mine.

Description of locality.—Nearly all of the small fragments were found at a point about ten miles southeast from Cañon Diablo near the base of a nearly circular elevation which is known locally as "Crater Mountain." I believe this is the same as Sunset Knoll figured on the topographical sheets of the U. S. Geological Survey. This is 185 miles (297.72 kilometers) due north from Tucson and about 250 miles (402.34 kilometers) west of Albuquerque.

The elevation, according to the survey, rises 432 feet (131.67 meters) above the plain. Its center is occupied by a cavity nearly three-quarters of a mile (1.2 kilometers) in diameter, the sides of which are so steep that animals that have descended into it have been unable to escape and have left their bleached bones at the bottom. The bottom seemed to be from fifty to one hundred feet (15.24 to 30.48 kilometers) below the surrounding plain. The rocks which form the rim of the so-called "crater" are sandstones and limestones and are uplifted on all sides at an almost uniform angle of from thirty-five to forty degrees. A careful search, however, failed to reveal any lava, obsidian or other volcanic products. I am therefore unable to explain the cause of this remarkable geological phenomenon. I also regret that a severe gallop across the plain had put my photographic apparatus out of order so that the plates I made were of no value.

About two miles (3.22 kilometers) from the point at the base of the "crater" in a nearly southeasterly direction, and almost exactly in a line with the longest dimensions of the area over which the fragments were found, two large masses were discovered within about eighty feet (24.38 meters) of each other. The area over which the small masses were scattered was about one-third of a mile (0.53 kilometer) in length and one hundred and twenty feet (36.57 meters) in its widest part. The longer dimension extended northwest and southeast.

Description of the specimens.—The largest mass discovered weighs 201 pounds (91.171 kilos.) and, as the photograph shows, Plate II, has a somewhat flattened rectangular shape showing extraordinarily deep and large pits, three of which pass entirely through the iron. The most remarkable example of such perforation is the Signet Iron from near Tucson, Arizona, now in the National Museum and figured in Prof. F. W. Clarke's Catalogue.[1]

[1] The Signet Iron was discovered about thirty miles (48.28 kilometers) from Tucson. Dr. Geo. H. Horn states that twenty-five years ago he was told by the Spaniards that plenty of iron could be found on a range of hills extending northwest and southeast half way between Albuquerque and Tucson.

One other large mass was found weighing 154 pounds (69.853 kilos.). This also deeply pitted. A mass weighing approximately 40 pounds (18.144 kilos.) was broken in pieces with a trip hammer and it was in cutting one of the fragments of this mass that diamonds were discovered. Plate I.

Besides these masses of considerable size a careful search made by myself with the assistance of five men was rewarded by the discovery of 108 smaller masses. Twenty-three others were also discovered making a total of 131 small masses ranging in weight from $\frac{1}{16}$ of an oz. (1.79 grm.) to 6 lbs. 10 oz. (3.006 kilos.).[1] A brownish white slightly botryoidal coating, found on a number of the meteorites, is probably aragonite.

A thorough examination of many miles of the plain proved that the car load of iron existed only in imagination. Accompanying the pieces found at the base of the "crater" were oxidized and sulphuretted fragments which a preliminary examination has shown are undoubtedly of meteoric origin. About 200 pounds (90.718 kilos.) of these were secured, from minute fragments up to 3 lbs. 14 oz. (or 1.757 kilos.). These fragments are mostly quite angular in character, and a very few show a greenish stain, resulting probably from the oxidation of the nickel. The oxidized material is identical in appearance with an incrustation which covers some of the iron masses and partially fills some of the pits.

Composition.—After obtaining the meteorite I was unable to return to Philadelphia for some time, and therefore sent a fragment of the 40 pound mass (8.144 kilos.) to Prof. G. A. Koenig for examination. Professor Koenig was compelled to leave town before this examination was completed. I take the following, therefore, from his letters to me and from an account furnished the daily *Public Ledger* by Dr. E. J. Nolan, Secretary of the Academy of Sciences, of a preliminary notice made by Professor Koenig, June 23, before the Academy of Natural Sciences of Philadelphia. In this account he says:

"In cutting the meteoric iron for study it had been found of an extraordinary hardness, the section taking a day and a half, and a number of chisels having been destroyed in the process. When the mass, which on the exterior was not distinguished from other pieces of meteoric iron, was divided, it was found that the cutting apparatus had fortunately gone through a cavity. In the attempt to polish the surface so as to bring out the characteristic Widmannstättian figures, Dr. Koenig received word that the emery wheel in use had been ruined.

On examination, he then found that the exposed cavities contained diamonds which cut through polished corundum as easily as a knife will cut through gypsum. The diamonds exposed were small, black and, of course, of but little commercial value but, mineralogically, they are of

[1]Oct. 18th.—During September I received three additional large masses weighing respectively 632, 506 and 145 pounds (or 286.678, 229.516 and 65 771 kilos.). The two latter were each perforated with three holes. A number of smaller masses up to 7 pounds, (3.175 kilos.) were discovered by digging. The three large masses and one of 23 pounds (10.432 kilos.) were covered with grass and earth.—A. E. F.

the greatest interest, the presence of such in meteorites having been unknown until 1887, when two Russian mineralogists discovered traces of diamond in a meteoric mixture of olivine and bronzite. Granules of amorphous carbon were also found in the cavity, and a small quantity of this treated with acid had revealed a minute white diamond of one-half a millimeter, or about $\frac{1}{5}$ of an inch in diameter. In manipulation, unfortunately, this specimen was lost, but others will doubtless be obtained in the course of investigation. The minerals troilite and daubréelite were also found in the cavities. The proportion of nickel in the general mass is three per cent, and the speaker was not as yet able to account for the extraordinary hardness apart from the presence of the diamonds in the cavities."

Professor Koenig in a letter to me gives the following points as definitely known.

"(1) *Diamonds*, black and white established by hardness and indifference to chemical agents. (2) *Carbon* in the form of a pulverulent iron carbide occurring in the same cavity with the diamonds. The precise nature of this carbide, whether containing hydrogen and nitrogen is not ascertained except in so far that after extracting all iron by nitro-hydrochloric acid, the black residue goes into solution with deep brown color upon treating it with potassium or sodium hydrate. From this solution acids do not precipitate anything. (3) *Sulphur* is not contained in the tough malleable portion of the meteorite but in the pulverulent portion. (4) *Phosphorus* is contained in the latter, and not in the former. (5) *Nickel* and (6) *Cobalt* in the proportion of 2 : 1 are contained in both parts nearly equally. (7) *Silicon* is only present in the pulverulent portion. (8) The Widmannstättian figures are not regular. (9) The iron is associated with a black hydroxide containing Fe, Ni, Co, P, in the ratio of the metallic part and therefore presumably derived by a process of oxidation and hydration of the latter."

Conclusions.—As this meteoric iron contains only 3 per cent of nickel while that from the Santa Catarina Mountains, 30 miles (48.28 kilometers) southeast of Tucson and 215 miles (346 kilometers) from this locality, contains from 8 per cent to 9 per cent, according to the analysis of Brush and Smith, they are quite distinct although somewhat alike in external appearance. They also somewhat resemble the Glorieta meteoric irons from about 300 miles (482.8 kilometers) to the east northeast, in New Mexico. These contain 11.15 per cent of nickel.

The most interesting feature is the discovery for the first time of diamonds in meteoric iron[1]. This might have been predicted from the fact that all the constituents of meteoric iron have been found in meteoric stones, and *vice versa*, although in different proportions.

The incrustations of what is probably aragonite shown by some of the

[1]Attention may be called to the discovery by Haidinger (1846) of cubic crystals of a graphitic carbon in the Arva meteoric iron and also of somewhat similar crystals from the Youngdegim, W. Australia iron, described by Fletcher (1887) under the name of cliftonite. Both have been regarded as pseudomorphs after diamond.

masses has rarely been noticed (I find two records by J. Lawrence Smith which he states to be unique, and both of these were from regions south of this one). The incrustation is especially interesting as showing that the meteoric irons must have been imbedded a long time, as the formation of aragonite would be exceedingly slow in this dry climate.

The remarkable quantity of oxidized black fragmental material that was found at those points where the greatest number of small fragments of meteoric iron were found, would seem to indicate that an extraordinarily large mass of probably 500 or 600 pounds (226.796 or 272.156 kilos.) had become oxidized while passing through the air and was so weakened in its internal structure that it had burst into pieces not long before reaching the earth.

Of the age of the Point Pleasant, Ohio, beds. By Prof. Joseph F. James, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

The strata about Cincinnati have been described by many authors since they were noticed by Dr. Drake in 1815. Among those who have written about them besides Drake are Vanuxem in 1829, who thought the rocks were of about the same age as those at Trenton Falls, N. Y.; Conrad in 1841, who made the same correlation; Hall in 1842, who referred the shale at Newport, Kentucky, to the Utica, and who said that a lower rock present might be the Trenton. In 1843 Hall referred the rocks to the Hudson River group of New York, and on the evidence of *Triarthrus beckii* he thought the Utica was also represented.

In 1865 Meek and Worthen proposed the term Cincinnati group which has been very generally used by western geologists. In 1873 Orton divided the Cincinnati group into three divisions, the lowest of which he called the Point Pleasant beds, and he assigned to them a thickness of fifty feet. These beds are below the lowest stratum at Cincinnati and have been the subject of considerable discussion,

A committee of the Cincinnati Society of Natural History with Mr. S. A. Miller, as chairman, referred these beds to the Trenton limestone, and this was followed by Linney of the Kentucky Geological Survey in 1882, and by Orton in the same year, the latter reference being based on the fact that the Utica is present in northern Ohio but runs out toward the Ohio river, and the Hudson rocks must therefore rest on the Trenton. This terrane he said was exposed at Point Pleasant. It does not agree, however, with facts given by well sections at Cincinnati, where Orton calculated the Hudson River and Utica together to be 235 feet below low water in the Ohio River.

A visit was made last year under the auspices of the U. S. Geological Survey to Point Pleasant to study the locality, and a section of 189 feet 6 inches was examined in detail. The section is given in full in the pa-

per, and the conclusion reached is that there is no evidence, either lithological, paleontological or stratigraphical to justify placing the Point Pleasant beds in the Trenton, unless the same disposition be made of the lowest rocks as exposed at Ludlow, Kentucky, opposite Cincinnati. The characters of the section at the latter place are the same as those of the lowest part of the Point Pleasant beds.

[The paper will be printed in full in the Journal of the Cincinnati Society of Natural History.]

ON PROBLEMATIC ORGANISMS AND THE PRESERVATION OF ALGÆ AS FOSSILS. By Prof. JOSEPH F. JAMES, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

Two opinions exist among geologists in regard to a certain class of fossils known as the "Problematic Organisms." One is that they are the remains of algæ or fucoids; the other the tracks or trails of animals, or possibly that they are of inorganic origin. Two subjects are treated of in the paper: (1) Absence of organic matter. (2) Probability of the preservation of algæ.

The absence of organic or carbonaceous matter is not considered, *per se*, to militate against the animal or vegetable origin of many of the forms, but when taken in connection with the absence of definite form, the position of the remains in the strata, and other circumstances, it is believed that the probabilities are greatly against not only the vegetable nature of many of the problematic organisms but also against their being the remains of animal forms.

Under the second head, the probability of the preservation of algæ as fossils, it is considered as undoubted that algæ have existed from the earliest geological period, but that they have been preserved as fossils is questioned. Seaweeds occur in great profusion in our seas and are frequently thrown up in great masses on the shores, but Lesquereux, who examined the question with great care, concluded they seldom retained their structure for any length of time. Matthew, however, thought that although they were not preserved in sand, they were in clay.

The problematic organisms are mostly found in strata devoid of other fossils, and in those whose appearance indicates deposition in shallow water. While this is the situation best suited for the growth of algæ, it is not suitable for their preservation. The loosely arranged masses of tissue are not adapted to withstand the abrading power of the water, and their presence in shallow water is not adapted to their preservation as fossils.

The final conclusion is that the probabilities that true algæ are included among the long list of species referred to the class from the lower rocks are infinitely small; while the chances that they are tracks, trails, burrows, or are due to inorganic causes, are almost infinitely great.

ON A NEW HORIZON OF FOSSIL FISHES. By Prof. E. D. COPE, Philadelphia, Pa.

[ABSTRACT.]

FIVE species of fishes obtained by the Rev. Wm. M Blackburn from the Ree Hills in South Dakota, have been described in the American Naturalist, 1891, p. 654, under the following names: Malacopterygii—*Gephyrura concentrica* Cope; *Sardinius blackburnii* Cope; *Proballastomus longulus* Cope. Acanthopterygii—*Oligoplarchus squamipinnis* Cope; *Mioplosus multidentatus* Cope. The first observation to be made on the species above described is that they differ as to species, and three of them as to genus, from all others discovered elsewhere, both fossil and recent. The next conclusion is that they include no Cretaceous types, the only identification with a Cretaceous genus (Sardinius) being purely provisional. The third point is that the genus Mioplosus has been found hitherto in the Green River Eocene only. The age is Cenozoic, but to which system the fauna belongs it is difficult to discover. None of the genera have been found in the Amyzon shales, and but one in the Green River shales, so that their pertinence to the Eocene fauna is doubtful. The chalky matrix much resembles that of some localities of the White River Neocene (Oligocene), and I should not be surprised if it should be found that this is the age of the fossils. It is likely that they were lacustrine in habitat.

Should the calcareous stratum in which these fossils are found not turn out to be an outline of the White River beds, I propose that they be called the Ree beds. They are overlaid, according to Dr. Blackburn, by a thin layer of the glacial drift.

ON THE CRANIAL CHARACTERS OF EQUUS EXCELSUS. By Prof. E. D. COPE, Philadelphia, Pa.

[ABSTRACT.]

A SKULL of *Equus excelsus* Leidy from the Equus beds of southwestern Texas was exhibited, and its characters pointed out. It is nearly complete, lacking the occipital region.

It was shown that it has the general characters of the quagga as distinguished from the horse; *i. e.*, the deeply excavated posterior nareal meatus and the short diastema and postdental part of the maxillary bone; but that it possessed some features not found in either. These are the prolongation posteriorly of the horizontal plate of the vomer; the externally narrow glenoid facet; the flat premaxillary symphysis; the lack of external grooves on the superior incisor teeth; and the small size of the last superior molar. In the last-named character the *E. excelsus* resembles the Hippidiums, and the three-toed horses.

FOSSIL TRACKS IN THE TRIAS OF YORK CO., PA. By A. WANNER, York, Pa.

[ABSTRACT.]

A SANDSTONE slab containing tracks found by Mr. Wanner in the Trias of York county, Pa., was exhibited.

One class of tracks the writer thought were made by some creature while swimming. The other tracks, consisting of parallel mounds of sand, were referred to the larvæ of insects.

NEW FOOTPRINTS FROM THE CONNECTICUT VALLEY. By Dr. M. M. MITIVIER, 206 High street, Holyoke, Mass.

[ABSTRACT.]

NEW footprints found on the rock of the Connecticut Valley about three miles from Holyoke, bearing evidence that the animals that made them were more closely allied to birds than to other animals; that the Dinosaurs are sketches of a new design and are further away from the reptiles than from the birds.

A STUDY OF THE FOSSIL AVIFAUNA OF THE SILVER LAKE REGION, OREGON. By Dr. R. W. SHUFELDT, Smithsonian Institution, Washington, D. C.

[ABSTRACT.]

DEVOTED to the description of a large collection of fossil birds discovered at the lakes of the Silver Lake region, Equus beds of Oregon, by Profs. E. D. Cope and Thomas Condon of the University of Oregon, in 1879. The major portion of the collection, including over 1,500 specimens, belongs to Professor Cope, who placed them in the hands of the writer for description. Fifty-one species are described, thirteen of which are new to science, thus comprising one of the largest collections of fossil birds in existence. Most of the forms are identical with existing species, but among the novelties are new gulls; a new *Branta;* an extinct flamingo (*P. copei*); an enormous anser (*A. condoni*); an extinct genus of a new grouse (*Palestetrix gilli* and a *Pediscætes* (*P. lucasi*); and many other highly interesting forms.

THE PLANT-BEARING DEPOSITS OF THE AMERICAN TRIAS. By Prof. LESTER F. WARD, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

THE plant-bearing deposits of the American Trias are, so far as known, confined to two general regions, viz., a series of troughs in the Piedmont

region of the Atlantic slope extending from Massachusetts to North Carolina, and a great basin or area in the territories of New Mexico and Arizona. The character and structural relations of these rocks have been fully discussed by numerous writers. It is proposed in this paper to examine the evidence of the fossil plants as to their geological position. This evidence may be considered from two points of view, first as to the relative position of the several basins, areas, or plant-bearing portions, and secondly as to the general relations of the flora as a whole to other floras which resemble it sufficiently to admit of comparison.

In looking at the subject from the first of these two points of view, or that of the *American distribution*, it is convenient to divide the general terrane into five geographical areas corresponding nearly with so many geological basins, viz., first, that of the Connecticut valley; second, the area that extends with little interruption from the Hudson river to near Charlottesville, Virginia; third, the Richmond coalfield; fourth, the North Carolina coalfield; and fifth, the western area which is not as yet sufficiently known to admit of subdivision.

The fossil plants have nearly all been found in the Connecticut valley, the Richmond coalfield, the North Carolina coalfield, and about the copper mines of New Mexico; a few come from New Jersey, Pennsylvania and Maryland, while only silicified trunks have thus far been discovered in Arizona. All the material that has been found has been carefully studied and as accurately determined as its nature will permit. The greatest abundance of vegetable remains occurs in the Richmond and North Carolina coal-fields.

A careful comparison of all the forms shows that out of a total of 119 species, eighty-five are confined to some one of the areas above enumerated, leaving only thirty-four that occur in two or more of them. Tables of the distribution of species with full analysis of their relations and significance are given in the paper. As a general result it is found that none of the basins except that of the west contains less than thirty-nine per cent of species common to it and some one or more of the other basins, and that one of them, viz.: that of New Jersey and Pennsylvania, has seventy-two per cent of its plants common to other basins, while that of North Carolina has fifty-two per cent and that of Virginia thirty-nine per cent. All who are familiar with the evidence from fossil floras must therefore admit that it is strongly in favor of the general parallelism of the four eastern basins, while the materials are too scanty to base a safe conclusion upon, relative to the great western area with fifteen per cent of its species common to it and the eastern deposits.

Considering the subject from the second point of view above mentioned, or that of the *foreign distribution*, it is found that forty of the one hundred and nineteen species occur in other deposits of the world, while seventeen others are represented elsewhere by closely related forms, giving fifty-seven of what may be termed diagnostic species. Omitting all details as before, it appears that the largest number of these, viz., thirty-two, occur in beds that have been authoritatively referred to the Keuper of Old World

nomenclature, the Rhetic coming next, with thirty-one, followed by the Lias with twenty and the Oolite with nineteen.

The general conclusion therefore is that, so far as the evidence from fossil plants goes, the precise horizon, relatively to the European deposits, of our American older Mesozoic plant-bearing rocks must be at the summit of the Triassic system, with their nearest representatives in the Keuper of Lunz in Austria and at Neue Welt near Basle, in Switzerland; while there is also a close affinity in the types to those of the Rhetic of Franconia and South Sweden.

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PRINCIPLES AND METHODS OF GEOLOGIC CORRELATION BY MEANS OF FOSSIL PLANTS. By Prof. LESTER F. WARD, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

THE value of paleontology to geology depends primarily upon the principles by which the paleontologist is guided in the application of his data, and secondarily upon the methods he adopts in bringing such data to bear upon the questions which geology presents for solution. This is especially true of paleobotany and the chief reason why that branch of paleontology has thus far been so little help to geology is that unsound principles or improper methods have been employed in reasoning from paleobotanical data.

Among the leading principles by which the paleobotanist should be guided may be mentioned the following:

1. Homotaxis. It should not be expected that widely separated deposits having similar floras are necessarily identical in age, since the present well-known laws of geographical distribution are likely to have been operative to a greater or less degree in past geologic ages, and the flora of the entire globe has probably never been homogeneous throughout. Different deposits may therefore be homotactically correlated without being contemporaneous, while on the other hand those having very different floras may have really been contemporaneous.

2. The great types of vegetation are characteristic of the great epochs in geology. This principle is applicable in comparing deposits of widely different ages where the stratigraphy is indecisive. For example, in rocks that are wholly unknown, even a small fragment of a Carboniferous plant proves conclusively that they must be Paleozoic, or a single dicotyledonous leaf that they must be as late as the Cretaceous.

3. For deposits not thus widely different in age, as for example, within the same geological series or system, ample material is necessary to fix their position by means of fossil plants. As this is the most common case it is the neglect of this principle that has led to the greater number of er-

o rs and done most to bring paleobotany into disrepute. Geologists have expected too much of paleobotanists, and the latter have done violence to the truth by attempting to satisfy the extravagant demands of the former. On the other hand, where the material is ample, fossil plants are as reliable as any other class of paleontologic data.

4. The correct systematic determination of fossil plants concerns biology and does not concern geology. Much of the disregard exhibited in some quarters for paleobotany has arisen from the impression that there is great uncertainty relative to the true nature of vegetable remains. This uncertainty is greatly exaggerated even by botanists who are apt to imagine that nothing can be known of a plant without having all its organs and parts before them. But the geologist need not be affected in the least by these discussions, since all that is required from his point of view is that the fossil be definite, constant, and easily recognizable, as is usually the case with plants. Such as possess these qualities and are also characteristic of a given deposit have their full diagnostic value independently of the question whether their true systematic position has been determined or not.

As regards methods in geologic correlation by means of fossil plants, it is chiefly important that the tables of distribution be complete and comprehensive, that is, that they embrace all the forms found elsewhere and that all the other localities and formations in which they occur be indicated. It is also important when comparing floras as ancient as the Mesozoic, that those species be enumerated which are obviously related to those of the deposit to be determined. In the discussion of such tables of distribution due regard should be had for the fact that the types of earlier floras often pass up into later ones, and when the latter are much more abundant than the former their occurrence argues much more strongly for the earlier than for the later date—for the Devonian than for the Carboniferous, and for the Cretaceous than for the Tertiary. Many serious errors have been committed by ignoring this principle.

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EXHIBITION OF CERTAIN BONES OF MEGALONYX NOT BEFORE KNOWN. By Prof. JAMES M. SAFFORD, Nashville, Tennessee.

[ABSTRACT.]

IN a lot of bones of Megalonyx found in Big Bone cave in Tennessee, enough of the pelvis was found to fairly well make out its form and characteristics. Heretofore, pelvis not known, the mere fragments found giving no satisfactory idea of it. Bones were found in 1884 in digging into a pile of bat manure the latter being used for fertilizing purposes.

Many years before this discovery another lot of bones were found in the same cave. These were described by Leidy in 1853. The bones of the last lot found supplement pretty well those described by Leidy and all may belong to the same animal.

A REPLY TO PROF. MARSH'S "NOTE ON MESOZOIC MAMMALIA." By Prof. HENRY F. OSBORN, American Museum of Natural History, New York.

[ABSTRACT.]

THE questions discussed in this paper relate to the structure and systematic position of a number of Mesozoic mammals, in which Prof. Marsh and the writer hold different opinions. These include the generic distinction of *Microconodon* from the Triassic; the characters of the jaw of *Phascolotherium* from the Stonesfield Slate Jurassic; the characters and validity of the order *Multituberculata*, proposed by Prof. Cope; the distinction of the family *Bolodontidæ* from *Plagiaulacidæ;* the structure of the type of *Stereognathus*, Charlesworth; the type of *Meniscoëssus*, Cope; the premolar of *Triglyphus*.

As to the Cretaceous mammalia defined and described by Professor Marsh, the writer holds that:

1. There is no evidence that the types of the family *Stagodontidæ* are really mammalian teeth.

2. That the order *Allotheria* is invalid because it has not been adequately defined and the termination *theria* has a sub-class significance.

3. That while there is no direct evidence, there is strong indirect evidence that the *Plagiaulacidæ* are characterized by upper molars with three rows of tubercles.

4. That *Allotheria* are known with three rows of tubercles in the lower molars is shown to be probable in the case of *Stereognathus*.

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ADDRESS

BY

PROFESSOR JOHN M. COULTER.

VICE PRESIDENT. SECTION F.

THE FUTURE OF SYSTEMATIC BOTANY.

In his presidential address before the Biological section of the British Association, in September, 1888, Dr. W. T. Thiselton-Dyer closed with the following words: "At the bottom of every great biological inquiry it has never been possible to neglect the study of plants; nay, more, the study of plant-life has generally given the key to the true course of investigation. Whether you take the problems of geographical distribution, the most obscure points in the theory of organic evolution, or the innermost secrets of vital phenomena, whether in health or disease, not to consider plants is still, in the words of Mr. Darwin, 'a gigantic oversight, for these would simplify the problem.'" If this broad claim be true, a botanical theme is an eminently appropriate one to present to a biological section. In the opinion of many, however, all kinds of botanical work are not equally bound up in the bundle of biological inquiry. It is for this very reason that I have selected as my subject, "The Future of Systematic Botany."

I know that it is unscientific to deal with the future, although our knowledge of the past and present becomes especially fascinating when we begin to turn it into prophecy. Moreover, upon occasions like this, it is more customary to review and sum up actual knowledge than to cast the horoscope of the future, although the latter is far easier. But, setting aside the custom of presenting either an interesting bit of research or a summarized view of information concerning some attractive subject, I would invite your attention to an ancient, and, to my notion, a much abused depart-

ment of work. It is perhaps well to say in the outset that the abuse to which I refer is not only that inflicted by Gentiles, but also by Jews; for often one's worst foes are those of his own household.

The ancient history of systematic botany is too well known to this audience to need even brief repetition, especially since the masterly sketch by Professor Sachs has found its place in all our libraries. The names of illustrious systematists are household words, and their various "systems" form a part of our training. The one desire which runs with increasing purpose through all this well known history is to reach eventually a natural system of classification. The one obstacle in the way of gratifying this desire has been a lack of knowledge. You remember the time when the knowledge of affinities was so slight that no attempt even was made to express relationships, and plants were simply systematically pigeonholed for future reference. The ingenuity of those days was taxed to construct the most convenient pigeon holes, and to properly assign to them the hosts of plants that were clamoring for recognition. Those who could thus properly assort a collection of plants, and could recognize when a new pigeon-hole was needed, were known first as "botanists" afterwards as "systematic botanists," an appellation proper enough, but one unfortunately not having sufficiently outgrown its original application. The unfortunate result of this necessity to so rigidly systematize facts and thus render them readily accessible was, as you well know, to make the pigeonholes as permanent as the facts they were intended temporarily to contain. A convenience at first became at last a tremendous hindrance, and we are even yet but slowly giving up our firm belief in the reality of the ancient pigeon-hole and its appropriate label. The fact is, that although our belief in them is oozing out, our necessities still compel us to use them; but it is to be hoped that they are being relegated rapidly to their proper position as conveniences, devices of semi-ignorance, and not considered as actual facts.

You also recall how knowledge presently became sufficient to justify an attempt at natural arrangement, crude enough, but still advanced enough to make an epoch in progress; and the authors of these first "natural arrangements" understood their own limitations better than anyone else. One natural arrangement has succeeded another, from that day to this, until in those of to-day we have

presented to us, simply what the earliest contained, viz. : the expression of man's knowledge of affinity; the difference being a slowly diminishing amount of artificial padding. I need not suggest to you how exceedingly imperfect that knowledge is yet, and how, of necessity, the best of our present systems must meet the fate of those that have gone before and become merely chapters in the history of systematic botany. This becomes doubly apparent when it is considered that "pigeon-holing" is going on almost as rapidly as ever; although we may fairly consider that we have now in hand sufficient material for the broadest generalizations. I say "material," not meaning by any means to imply the knowledge which proper investigation of this material is to bring us.

Systematic botany, as formerly understood, has probably done all that it can unaided in the natural arrangement of plants. Of course it could indefinitely juggle with sequence and nomenclature, but, after all, that is like arranging a card catalogue, and is of such secondary importance, when the real purpose of systematic botany is considered, that it can hardly be taken as indicative of progress. Let me interject a word at this point. It is my impression that the decriers of systematic botany have only in mind this "juggling with sequence and nomenclature" when they make their strictures, and are mistaking the art of the tailor for the evolution of the real man. One must be respectably clothed, but he must be an unspeakable idiot if that is all that can be said of him. It has always been my impression that the depreciation of any other kind of scientific work argues either lack of knowledge or conceit.

But the ancient kind of systematic botany was not left without aid, and a group of new departments was made possible by the microscope and the unexampled progress of powers and manipulation. The study of the cell, and of nascent and mature organs, and the recognition of plants as living things that are the resultant of the interplay of internal and external forces, have simply revivified the ancient mummy called Botany, and have made it the living thing it is to day, capable of endless development. It is not to be wondered at that these new and vigorous departments of work, in the first glow of the vital service they have rendered, should look at the older departments as a thing of the past, as something to be buried out of sight. But this is only the first glow of a natural enthusiasm, and I glory in it, for it promises an enormous amount of self-denying work, and the results will all fall

nto the lap of Systematic Botany. The corpse is not buried, but revivified, and the gush of new work has been but the infusion of an elixir of life into a body that was perishing from starvation.

Some one has said that "the highest reach of the human mind is a natural system of classification;" and Professor Thiselton-Dyer, in the address quoted at the opening of this paper, remarks that "such a classification, to be perfect, must be the ultimate generalization of every scrap of knowledge which we can bring to bear upon the study of plant-affinity."

This simply means that when the results of all departments of botanical work are well in hand then the systematists will be in a position to put on a sure foundation the structure they have always been planning, for it will rest upon known affinities and not upon unmeaning resemblances. To my view, therefore, the real systematic botany is to sum up and utilize the results of all other departments; and its work, so far from belonging entirely to the past, is well nigh all in the future. It is the highest kind of generalization upon an enormous array of facts, and is bound to be the *last* expression of human thought with reference to plant-life, just as it was the *first*. Systematic botany, therefore, the sytematic botany which deals with genetic characters, and recognizes the fact that every plant is a living thing with a history and all degrees of consanguinity, and that the "final form of every natural classification must be to approximate to the order of descent," is in its early infancy, and can only develop to completest power when all the facts of plant origin, structure and life are in. This would seem to make it a slowly developing department of a somewhat endless future, with every distinct advance in knowledge embodied in some "Natural System."

These invaluable "systems" will well stand for a series of approximations towards the truth, each succeeding one probably somewhat nearer than the one before, but still far enough removed to stimulate further research.

My position, therefore, is that for the systematists of to-day and of the future there must be three distinct lines of work, related to each other in natural sequence in the order in which I shall present them, and each turning over its completed product to the next.

I. The collection and description of plants. This *preliminary phase* of systematic botany is that which most frequently stands for the whole, especially in the minds of those who have been trained

in that ancient fashion. It is really strange why this particular and very necessary phase of systematic work has gotten into disrepute among the younger botanists; and I can explain it only by the fact that it is the oldest representative of the science, or that it so frequently stands for all of botanical science in the popular mind, and this popular verdict is resented. With this last position I am thoroughly in sympathy, and it is perfectly proper for the public mind to be disabused and made to understand that botany is a science of living things and not merely of mummies; but this can be best done by treating courteously the ancient and ever to be present and necessary work of collection and description. Such workers are curators of botanical material upon an extensive scale, a function that, properly exercised, requires a skill and patience that few possess but that many assume.

I grant that the discovery and description of new species are such an inspiring pursuit that it may degenerate into a mania, and sometimes into kleptomania; but the worst of it is that it attracts many who are wholly incompetent, and who have burdened our literature with rubbish that is both discreditable and confusing; but this can be no more true of this than of any other phase of botany or scientific work. I do not desire to be understood as defending this kind of botanical work, for it needs no defence of mine; but simply, in view of certain fraternal thrusts that have been given, less frequently now than formerly, to call attention to the fact that this is one of the living and necessary kinds of botanical work, subject, like all other kinds, to degradation at the hands of its friends.

While I have spoken of this phase of botanical work as the most ancient, and one which, like the poor, we are always to have with us, I by no means intended to imply that its methods cannot be improved. It must have long since occurred to some that many things besides the mere sporadic collection and recording of species should be included as legitimately belonging to this line of research. It is the common plan to collect and record a plant in such an isolated way that it becomes a text without any context, and is thus robbed of much of its significance. Collectors send in from the field large amounts of miscellaneous material and usually the only accompanying information is a locality, mostly very indefinite, and a date. In some cases the size and habit are appended, and possibly some local economic note. I take it that this fairly represents the average amount of information obtained from filed

contact with species; and how meagre and unsatisfactory this is can only be appreciated by one who undertakes to make a thorough study of the flora of any region. I have no fault to find with the facts, so far as they go, but they are not half that we have a right to expect from the expenditure of time and energy. There seems to be nothing more unsystematic than field-work in systematic botany. The result is that we know a little about all our floral regions, and all about none, however small. All information that can be obtained in the field concerning species is the province of the collector to procure and of the taxonomist to record. This additional information is important, not merely as additional information, but frequently in correcting errors of judgment concerning species. A species surely holds important relations to its environment, and its characters in some unusual position, or in the penumbra of its range, can hardly be taken as typical; and yet this thing of range and relative abundance, involving centres of distribution, is rarely looked after. What I protest against is the search for species as for diamonds, as things solely valuable in themselves apart from their surroundings; and what I would urge is the conversion of collecting trips into biological surveys. I know that this means the better training of collectors, that they must be not mere manipulators of drying paper, but scientific men; but is that any objection? I would not for a moment disparage the work of that splendid array of collectors who have triumphed over innumerable difficulties in a self-denying way worthy of any cause, and who have brought to light a wealth of material for which we can never be too grateful; but I would claim that the time has now come when the same amount of devoted labor can be expended to better advantage; and that we must train up a race of field-workers who shall follow their profession as distinctly and scientifically as the race of topographers. In this centre of public scientific work in which we have met, devoted to obtaining the largest amount of information in regard to our material possessions, and with means commensurate with the largest plans, it seems an appropriate thing to urge a thoroughly equipped system of biological surveys. This subject is not a new one here, and steps have already been taken to organize some work of this kind, but I desire to voice the sentiment of this section in commending all that has been done in this direction and in urging that the organization be made more general and extensive.

With regard to the work of description, I have little more to say

than to express a feeling of regret that it is not always wisely done This feeling, however, is not peculiar to any kind of work, and it must be always a jumble of good, bad, and indifferent. It is simply a case of "let him that is without sin among you first cast a stone," and the man who publishes nothing that he afterwards regrets is either a transcendent genius or a simpleton. It might as well be accepted, however, that description will continue as before, probably in an increasingly miscellaneous way, for there is no feasible way of restricting it, even if it were desirable. We can simply urge, and continue to urge the necessity of long training, abundance of material and literature, and a patience that will be content to wait. Dr. Asa Gray, in a short paper that has never been published, has this to say: "The publication of new species is always an anxious business to those fitted for the work and impressed by the responsibility of it, and is lightly undertaken only by those who have no appreciation of the trouble and labor they are giving to the faithful working botanist, both now and hereafter. Some enter upon this seemingly in the spirit in which an ill-disposed person was recommended to throw as much dirt as possible, on the chance that some may stick. The aggrieved author of monographs, floras, and bibliographical indexes has all this dirt (matter out of place) to take care of. He has enough to do in rightly arranging and ascertaining the limits and characters of the species of a difficult genus, without being vexed with riddles which, when solved, often prove to be curiosities of ignorance or marvels of recklessness. The added misfortune is that superfluous names, however needless or absurd, cannot be buried in oblivion, but must be embalmed in synonymy."

There seems to be abundant indication that with a better conception of the limitations of a species the old characters will yield in importance to new ones of deeper significance. The microscope, which was necessary to reveal the existence of any usable characters in the lower groups of plants, is rapidly becoming hardly less necessary for satisfactory systematic work in the highest groups. While the use of gross organs will probably never disappear in scientific discriminations, their *exclusive* use must be given up, and such characters will be supplemented by minute ones, which their very minuteness renders of more permanent diagnostic value. You are all familiar with several troublesome groups, in which minute characters have already been made of great service in steadying characters obtained from the gross, the largely

used, and hence the variable organs. I look upon this as one of the most promising features of the work of future taxonomists of the higher groups.

The serious danger lurking just here is that when one set of characters has proved serviceable in a number of specific or generic limitations, the tendency is to make the fabric of the whole group conform to that one set. This gives, of course, a kind of mathematical precision, and every problem is solved by the same formula. But, unfortunately, nature never conforms to such arbitrary rules, and the resulting arrangement may be as purely artificial as those that are confessedly so. The character of a species is an extremely composite affair, and it must stand or fall by the *sum total* of its peculiarities and not by a single one. A specific character in one group may be a generic character in a closely related one, or no character at all. Therefore, there is nothing that involves a broader grasp of facts, the use of an inspiration rather than a rule, than the proper discrimination of species. I have a belief that the arbitrary, rule-of-three mind will never make a successful taxonomist; and that there is a sort of instinct for specific limitations which the possessor cannot communicate to another. This taking into account the total character of a plant, from *facies* to minute characters, will furnish the basis of future descriptive work. The more obstacles that can be put in the way of hasty determination the better.

I have dwelt thus upon the work of collection and description both to magnify it and to indicate that its proper position is that of a preliminary phase in the study of Systematic Botany.

II. The study of life-histories. A second phase of Systematic Botany may be called the study of life-histories. It follows the former in natural, as well as historical sequence, and curiously enough, its votaries do not usually class themselves with systematists although their work is chiefly an attempt to discover affinities. True, they deal in the main with the larger groupings, but this is only possible when a wealth of species is at hand. By "life-history" I do not mean simply that gross observation which watches a plant from germination to maturity, although that must be considered an extremely useful service; but even more that minute tracing, cell by cell, from the primitive cell to the mature plant, a work which is now conceded to reveal more of the deep secrets of affinity than perhaps any other. The tremendous amount of material to be thus investigated, and the numerous obstacles to be

overcome, have been the chief stimulus of recent botanical activity; and there has sprung into existence a race of workers whose powers of manipulation are little short of marvelous. These observers are bringing the hidden things to light, and out of the facts they are accumulating is to be constructed the Natural System. But the field is comparatively a new one, and the material so exhaustless that it can well satisfy the ambition of the most diligent. I would consider this work of searching for the affinities of great groups the crying need of systematic botany to-day. The need is so evident, and the work so attractive, that there is no lack of numbers in those who are undertaking it. The multiplication of facilities for this work is all that could be asked; but too often "facilities of work" and a little knowledge of technique are considered to be the only things necessary for this difficult kind of investigation. The consequence is that "life histories" have been published which are not histories of any living thing. The amount of work to be done is so great, and the use to be made of the results is so important, that incompetent work is peculiarly exasperating. Nothing is more capable of misinterpretation than are the observations made in work of this nature, and the tendency to generalize upon few or even doubtful facts is a constant temptation.

It is really a question as yet, whether, even among skilful investigators, too much stress is not laid upon certain single characters, and the sum-total of development not sufficiently considered. There is a marked tendency to select certain parts of certain organs and square the affinities of the whole organism by these, rather than to consider them in the light of cumulative testimony, to be used in connection with others. The tendency is not pernicious, for it is rapidly accumulating a vast amount of partial testimony, but the broadest generalizations concerning affinity cannot be made until every part of every organ is considered, and the position of the organism be made the resultant of all.

There is no question but that certain periods in the development of a plant, or certain important organs, notably the sexual ones, are freighted with deeper meaning than others and rightly exercise a dominating influence in determining affinities; but development at every period, and of every organ, must eventually be taken into account before the last word can be spoken concerning a natural system. The possibilities of adaptation seem so great that it is possible to conceive of two forms closely related in fact, but widely separated by some scheme which depends upon any one set of or-

gans however dominant. For example, this trouble has been experienced over and over again in all presentations of Thallophytes, and will probably continue to be experienced as long as some single key is used to unlock all the mysteries of affinity. I cannot see why a single set of characters used by an embryologist may not result in as artificial a scheme as the use of two or three organs by the taxonomist.

I have thus spoken of the study of life-histories to indicate that its chief function lies in the field of systematic botany; to suggest that it take into account development at every period and of every organ and so obtain a mass of cumulative evidence for safe generalization; and to urge upon those not thoroughly equipped great caution in publication.

I fear that what has been said concerning the great difficulty of the work of the two phases of systematic botany already mentioned may be taken to imply that there is nothing here for the poorly equipped but well-intentioned to do. My frank opinion is, that there is an abundance of service that such can render, and that their chief function is to bring facts to the notice of those who know how to use them. Very few of us can hope to be architects, but almost any one can carry brick and mortar.

III. The construction of a natural system. This is, of necessity, the last phase of systematic botany, and it is evident that its work will not be complete until the two previous kinds of work have been exhausted. The fact is, it must lay under tribute every department of botanical work and be a compendious expression of man's knowledge of the affinities of plants. It is just here that the work of the tyro is most common and least harmful; for crude systems need not annoy, they can be buried and no law requires their embalming; no necessity compels a verification of their facts, for no facts are used except such as are already known. I venture the assertion that few botanists can truthfully deny that in the early and most ambitious stage of their development they either had in mind, or were rash enough to publish some idea that was to simplify the whole scheme of plant arrangement. This tendency may have soon been checked by wise friends or sad experience, but to attack the largest problems first is as natural as youth itself. I speak of this, not only as a generalization, but also as a reminiscence.

But these Phaeton-like attempts aside, wherein lies the necessity of this most difficult work before the facts are all in, this attempt-

ing what is conceded to be impossible? Is it of any advantage to construct a system to-day which must be found faulty to-morrow? It is of the highest advantage to construct any system which shall embody every known fact concerning affinity. Every such system becomes, as ought to be clearly understood, simply an expression of our imperfect knowledge, a convenient summary of information, a sort of mile-post to tell us how far we have come and to direct future effort. In his essay upon "The significance of sexual reproduction in the theory of natural selection," Weismann uses these words, which are well worth quoting in this connection: "Instead of comparing the progress of science to a building, I should prefer to compare it to a mining operation, undertaken in order to open a freely branching lode. Such a lode must not be attacked from one point alone, but from many points simultaneously. From some of these we should quickly reach the deep-seated parts of the lode, from others we should only reach its superficial parts; but from every point some knowledge of the complex *tout ensemble* of the lode would be gained. And the more numerous the points of attack, the more complete would be the knowledge acquired, for valuable insight will be obtained in every place where the work is carried on with discretion and perseverance. But discretion is indispensable for a fruitful result; or, leaving our metaphor, facts must be connected together by theories, if science is to advance. Just as theories are valueless without a firm basis of facts, so the mere collection of facts, without relation and without coherence, is utterly valueless. Science is impossible without hypotheses and theories; they are the plummets with which we test the depth of the ocean of unknown phenomena, and thus determine the future course to be pursued on our voyage of discovery. They do not give us absolute knowledge, but they afford us as much insight as it is possible for us to gain at the present time. To go on investigating without the guidance of theories, is like attempting to walk in a thick mist without a track and without a compass. We should get somewhere under these circumstances, but chance alone would determine whether we should reach a stony desert of unintelligible facts or a system of roads leading in some useful direction; and in most cases chance would decide against us."

It becomes very evident that the work of constructing even a natural system which must be tentative, a sort of temporary scaffold, is one which demands not only the widest range of information, and hence a task which is daily becoming more exacting, but

also that broad grasp in generalization which is possessed by very few. The marshalling of facts is like the marshalling of armies, and very few are born generals. Almost any one can arrange the plant kingdom who is possessed of but few facts, but he who has them all within his reach finds no more difficult task, for it is like fitting together a puzzle of endless pieces.

The question might arise as to the duty of ordinary manuals in this respect, books of limited range, that do not profess to undertake such a path-breaking operation as the construction of a new natural system. It has always been my opinion that even the most local manual should be an expression of the ascertained facts of affinity. This statement is by no means so sweeping as it may at first appear; for it does not contemplate including the scores of crude notions which are always being advanced, so attractive to many who are naturally restless and mistake change for progress. In the statement made, I desire to emphasize the words "ascertained facts of affinity;" and this is very far from permitting the use of every random notion that may happen to be published. The facts of affinity are slowly accumulating, facts which have reached the dignity of general consent, and it is such that I would always have incorporated even in local manuals, which should not be subjected to the continuous shaking of treacherous ground. I am fully aware that there is a conservatism which is an obstruction to progress; just as there is a galloping rapidity which would land us in the mire; and that we probably all possess one of these qualities in our anxiety to escape the dangers of the other.

The points presented then, in this consideration of the third phase of systematic botany, are that the last and highest expression of systematic work is the construction of a natural system based upon the accumulations of those who collect and describe, and those who study life-histories; that this work involves the completest command of literature and the highest powers of generalization; that it is essential to progress for a natural system to be attempted with every advance in knowledge; and that all the known facts of affinity, thus brought within reach, should be expressed in all systematic literature.

In conclusion, I have but to say that I have attempted to indicate the true relation which exists among the different phases of systematic botany; to point out an affinity which there is danger of ignoring; and to maintain that all these departments of work, looking to the same end, are equally important, equally honorable.

PAPERS READ.

TRANSPIRATION, OR THE LOSS OF WATER FROM PLANTS. By Prof. CHARLES E. BESSEY and ALBERT F. WOODS, University of Nebraska, Lincoln, Nebr.

[ABSTRACT.]

IN this paper we propose to give some idea of the work accomplished by different investigators, the results reached by them, and to set forth in as concise a form as possible the present condition of the problem of water-loss from vegetation. It is not our purpose to attempt to pronounce finally upon disputed propositions, nor to report the results of an exhaustive reëxamination and reinvestigation of the subject. This paper, therefore, lays no claim to originality: it is simply a report upon the condition of one of the problems in botany.

In its preparation, free use has been made of the admirable papers by Dr. Alfred Burgerstein, published in the transactions of the Royal Zoological-Botanical Society of Vienna, in 1887 and 1889, and modestly called by him "Materials for a Monograph relating to the Phenomena of Transpiration of Plants."[1] They contain excellent summaries of two hundred and thirty-two papers upon transpiration, and extending over a period of two hundred and seventeen years. These with subsequent papers by other authors, and the discussions in the standard botanical works consulted, easily bring the list up to two hundred and fifty, or more.

HISTORICAL SUMMARY.

The first definite observations on the loss of water from plants were made in the latter part of the seventeenth century by Woodward in England, and Mariotte in France. In the eighteenth century, Hales in England, and Guettard, Méese, and Sénébier in France made more extended observations on the amount of water lost by plants under various conditions of light, temperature, moisture, etc. Daubeny in 1835 published some of the results of his investigations upon the influence of different colored light rays upon the "exhalation of moisture from leaves." It is interesting to notice that at this early date this investigator came to the

[1] *Materialien zu einer Monographie betreffend die Erscheinungen der Transpiration der Pflanzen.* I Theil, 1887; II Theil, 1889.

conclusion that the exhalation of moisture from the leaves, and the absorption of water by the roots "are probably dependent on the combined action of heat and light, coupled with those mechanical influences, which operate upon dead, as well as upon living organic matter."[1] Garreau a few years later determined the relative amounts of exhaled water for the upper and under surfaces of leaves, especially with reference to the number of stomata.[2]

For the past thirty or forty years the publications have been so numerous that it is impossible to do more than indicate the general lines of investigation, and to mention a few of the most important authors.

Guttation, *i. e.*, the exudation of water from stomata and water-pores, has been studied especially by Langer (1879), Moll (1880), and Volkens (1883).

Water-loss through leafless twigs, by Th. Hartig (1863).

Water-loss through lenticels, by Stahl (1873) and Kleben (1883–4).

Influence of leaf-structure, by Garreau (1849), Unger (1862), Sachs (1861), Wiesner (1879), Fr. Haberlandt (1877), Von Hoehnel (1878), Merget (1878), and Vesque (1878).

Stomata, by Mohl (1856), Unger (1857), Schwendener (1882) and Kohl (1886).

Relation of Transpiration to Leaf-fall, by Wiesner (1871) and Molisch (1886).

Transpiration of the flower, by Wiesner (1882).

Influence of light, by Déhérain (1869), Wiesner (1876), Comes (1878), Hellriegel (1883), and Henslow (1885).

Influence of the dark heat-rays, by Wiesner (1876), Vesque (1876), Henslow (1885), and Eberdt (1889).

Influence of air-temperature, by Hellriegel (1883), and Tschaplowitz (1883).

Influence of air-humidity, by Sorauer (1878), Hellriegel (1883), Leclerc (1883), and Tschaplowitz (1882).

Influence of air movements, by Wiesner (1887) and Eberdt (1889).

Influence of food materials, by Sachs (1859–60), Burgerstein (1876–78), Nobbe (1864) and Sorauer (1880–82).

Influence of soil-temperature, by Sachs (1859).

Influence of soil-water, by Hellriegel (1883).

Periodicity of transpiration, by Eberdt (1889).

Influence of various protective devices, by Tschirch (1880–82), Johow (1884), and Volkens (1886).

Influence of anæsthetics, by Jumelle (1889–90).

METHODS OF OBSERVATION.

The loss of water from plants in a given time has been determined in three general ways: (1) Woodward measured the amount of water taken up by the roots, and considered this to be a measure of the transpiration. This

[1] Philosophical Transactions, 1836, p. 159.

[2] Ann. Sciences Naturelles, Bot. 3 series, Vol. 13, p. 335.

method has been shown by many observers to be misleading; the amount of water transpired is not necessarily proportional to the amount absorbed. (2) Mariotte and Guettard collected and measured the water exhaled. This method while theoretically perfect is objectionable on account of the difficulty of maintaining normal conditions within the collecting vessels. (3) Hales weighed the plant at certain intervals and noted the loss in weight. This method has been most generally used by investigators. Apparatus similar to that used by Kohl and Eberdt allows the best control of conditions. A glass jar having three openings in the top, or two in the top and one in the side, is provided. In one of the top openings the plant is fixed; in another a thermometer is placed; in the third is fixed a small-bore graduated tube open at the upper end. The jar is filled with a culture medium. The water in the graduated tube is kept at a height a little above that in the jar. Record is kept of the temperature of the air, the temperature of the culture medium, the humidity of the air, the absorption of the water by the roots (measured by its lowering in the graduated tube), the loss of weight, conditions of light, air currents, etc.

WHAT IS TRANSPIRATION?

In the first place it is necessary to know with what restrictions the term transpiration is used, inasmuch as no small amount of confusion has arisen on account of a neglect of this precaution.

Du Hamel and Sénébier pointed out two kinds of water-loss, viz.: (1) imperceptible vaporization; (2) perceptible vaporization, the latter including the excretion of water-drops, resin, honey dew, etc.

Berthelemy recognized three kinds of water loss, viz.: (1) insensible exhalation through the cuticle; (2) exhalation or emission of highly saturated gas through the stomata; and (3) the exhalation of water, or the secretion of drops.

Von Hoehnel made use of the terms "cuticular transpiration," and "stomatic transpiration" for the first and second respectively of Berthelemy's classification, and these are practically the same as Wiesner's "epidermal transpiration" and "intercellular transpiration."

Burgerstein observes that under "transpiration" is generally included only the water-loss in the form of vapor, and remarks that this definition is, strictly speaking, not precise, and that, also, the excretion of fluid water from the stomata and water-pores (guttation) "is unquestionably a transpiration phenomenon."

On the other hand Van Tieghem restricts "transpiration" to the water-loss of chlorophyll-less organs or tissues. It increases with the intensity of the light, but is not dependent upon it.

Again it is held by some that there are two kinds of water-loss, viz.: (1) that which is purely physical and therefore called "evaporation;" and (2) that which is physiological, to which the name "transpiration" is restricted.

With these varying uses of terms it is difficult to determine precisely in all cases what an author actually wishes to convey. This confusion of

terms is much to be regretted, but it will doubtless continue until writers take pains to restrict all the terms they use.

Using the term "transpiration" in its widest sense, we come now to the question as to whether it is a physical or a physiological phenomenon. We remark, first, that if a physical phenomenon it may well be called "evaporation," there being no valid reason for the use of any other term. If, however, it can be shown that the water-loss is a physiological phenomenon, it must bear a distinctive name, and that of "transpiration" is as good as any.

DeCandolle, Schleiden, Nägeli, Unger, Baranetzky, Eder, Masure, Leclerc, Tschaplowitz, Van Tieghem and Volkens consider transpiration to be a physical phenomenon.

Dutrochet, Hartig, Déhérain, Wiesner, Von Hoehnel, Bonnier, Sachs, and Kohl consider it to be physiological.

Wiesner and Van Tieghem although disagreeing as to the nature of transpiration, arrive at practically the same conclusions as to the effect of light. That vaporization which is the result of the absorption of light by chlorophyll they both distinguish as "chlorovaporization," Wiesner has shown that etiolin, anthokyan, etc., absorb light, and convert it into heat, thus producing an elevation of the temperature of the tissues, and a consequent increase of vaporization. This he includes, also, under chlorovaporization. Wiesner has shown, further, that protoplasm with its contained water, converts light into heat, thus producing what he calls "protoplasmavaporization." Van Tieghem and others have shown that cells destitute of protoplasm exhibit nearly similar transpiration phenomena to those containing protoplasm.

Although Burgerstein interprets these results as indicating that transpiration in Van Tieghem's sense is a function of protoplasm (as respiration is a protoplasmic function), and that chlorovaporization is a function of chlorophyll (as carbonic acid assimilation is a "function chlorophyllienne"), a critical examination indicates the physical rather than the physiological nature of both these instances of transpiration. Chlorovaporization may be (but is not proved to be) an inseparable, though valueless physical accompaniment of assimilation. In the same way, protoplasmavaporization of Wiesner, and transpiration in Van Tieghem's sense, may be an inseparable though valueless physical accompaniment of respiration.

That all the phenomena in vegetable physiology depend ultimately upon purely physico-chemical laws is evident, as was first demonstrated by Nägeli. In one sense all these phenomena of transpiration are unquestionably physical. Whether there are transpiration phenomena which have in themselves a definite relation to the normal undoubted vital activities of the cell, or of the organism, remains yet to be proved. In the investigation and discussion it must be borne in mind that proof that one phenomenon of transpiration is physical, is no proof of the physical nature of others, and, moreover, it must be remembered that an activity which is purely physical for the individual cell, may be physiological for the whole organism. It is therefore quite probable that we shall find certain of these transpiration phenomena to be physical, and others physiological.

MOVEMENTS OF FLUIDS IN PLANTS. By Prof. W. J. BEAL, Agricultural College, Michigan.

I HAVE thought it best at this time to confine my remarks to the movements of fluids in flowering plants, and of these more especially exogenous trees. If we can understand the operation as it occurs in a tall tree, there will usually be less difficulty in understanding what takes place in smaller plants which have a less complex structure.

Professor Pammel has shown how water gets into the plant through the roots and shows that this water holds in solution small quantities of salts, gases and other nutrients.

Dr. Arthur has demonstrated that gases are absorbed in considerable quantity through the stomata.

To bring together the materials absorbed at the extremities of plants and account for the changes that take place is a complex problem. The movements of fluids in plants may naturally be considered under two headings:

1. The channels or the course taken by the fluids.
2. The causes or the methods of accounting for the movements.

In considering the first part of the subject,—we learn by examination that all sorts of cells in the interior of plants contain pits or thin places and these pits we suppose contain numerous minute holes. Especially are the pits to be seen in cells which have acquired thick walls.

I take it for granted that no one here will dispute the remarkable statement made by Sachs in 1880; that "every plant, however highly organized, is fundamentally a protoplasmic body forming a connected whole."

We see, then, whenever any occasion demands it, such as changes of light, heat, or metabolism there are numerous passages or open doors, through which fluids can pass in almost any direction throughout the plant.

If the bark for some distance be all removed around a tree, water continues to ascend freely to the leaves above. Then, if a circle of alburnum be removed the tree dies very soon.

This seems to show pretty conclusively that water ascends a tree mainly, if not exclusively, in the alburnum.

Sachs appears to have proved that the large-celled spring wood of each year, is a much better conductor of water than the smaller thick-walled cells of autumn; also that the spring wood of each layer acts in the main independently of that in each other layer.

Elsewhere[1] Sachs frequently states that water passes up through the substance of the cell walls and not in the lumena or cavities. Unger, in 1868, held the same view and both believe they sustained their views by experiments.

If the latter view were tenable, I should suppose that water could pass more rapidly and in greater abundance where the cell walls were thickest: viz., in the autumn wood of each year.

[1]Uberdie Porosität des Holzes (Arb. des bot. Inst. in Wzbg. 1879).

I repeated the experiment of reviving a wilted plant by using mercury in a U-tube with the usual results. Boehm[1] found that it took a much greater pressure to drive water across the stem, either tangentially or radially, than it does to drive it in the direction of the long axes of the elements. He showed this by cutting cylinders of fresh wood in three directions, and attempting to force water into them by the U-tube and mercury.

Sachs refers to the rapidity with which water passes through a stick of fresh wood, in either coniferous or that of deciduous trees. Before the buds had made much progress in May, I was unable to cause water to pass through a freshly-cut stick of arbor vitæ which was three feet long. A straight limb of silver maple three feet long with a diameter of an inch or more responded very promptly. In a mild day a few drops of water were placed on the upper end of the stick where it rapidly disappeared; in five to fifteen seconds, water appeared at the lower end of the stick. It made no difference in the result if the stick was inverted. In a cool day with the thermometer at 40 F. after the leaves of the maple had appeared, I was unable with two or three specimens to induce the upper freshly-cut end to absorb water. On warming the sticks for half an hour or more wetting the ends every little while, I was still unable to see any water absorbed when placed on the upper end of a stick. Boehm[2] has shown that the cavities of the ducts of heart wood are blocked up by means of *tyloses*,—ingrowths of surrounding parenchyma-cells which push through and fill the cavities with a spurious tissue, and it is they also which gradually block up the vessels of cut branches.

Unger, Pfeffer and Sachs[3] are exponents of the theory that water passes through the walls of wood cells, while Hartig, Naegeli, Schwendener, and Boehm are the chief adherents to the view that water ascends in the cavities of the vessels and tracheides. Hartig showed that water could be blown or sucked through short pieces of fresh wood of yew or pine wood. By the use of a U-tube he found water could be blown through the alburnum of the yew and not through the heart wood. This was shown by using eosin in the water and examining a section of the wood after making the experiment, to find the alburnum dyed.

By turning fresh cylinders of green wood of the yew which is destitute of resin passages, in three directions, Elfving found by the use of mercury and the U-tube, that he could easily force eosin in the longitudinal cylinders of the alburnum; the tangential cylinders allowed the eosin to filter through slowly; but not a drop could be forced through the radial cylinders under a pressure of 17 cm. of mercury. In other words, water will pass readily in the direction where there are bordered pits, but not in the direction where these are nearly all absent. If water passes through the body of the walls of wood, as Sachs and some others believe, why was Elfving unable to force it through in the direction where there were no pits?

Again, Elfving placed eosin in cacoa-butter and forced it into the lower end of a freshly-cut stick of yew, where the lumena of the tracheides were filled. Then on cutting the end again freshly, he found it impossible to

[1]Timber and some of its Diseases. By H. M. Ward, p. 72. [2]Ward, p. 75. [3]Ward, p. 77.

force water up the stem, as he might do, did water pass up the body of the cell wall. Some criticise the use of a greasy substance to stop the cavities of the wood cells.

Scheit and Leo Errera[1] employed gelatine colored with eosin and completely confirmed Elfving's results. Fresh branches after this treatment were newly cut at the tip and placed in water. The fresh leaves on the twigs speedily wilted showing that they were unable to draw water through the body of the wood cells.

I repeated on two occasions the latter experiments on two branches of the lilac, containing full grown leaves. The branches were cut while submerged in warm gelatine containing eosin. Radial and cross sections both showed that the eosin was present mainly in the pitted vessels, and to some extent in the wood parenchyma and tracheides. None was seen in the buds nor in the pith. The branches could not be made to revive, even when the tips were newly cut. The eosin passed up the pitted vessels about 1,5 cm.

In considering the second part of my subject, as to the methods by which water is induced to move through the plant, we see the pits and ducts, but to understand all the causes for movements is most difficult to demonstrate. Even with all the experiments devised by the shrewdest physiologists, much remains to be explained by various theories, with some of which all botanists are not fully satisfied.

If schemes can be devised whereby water can be raised to the top of a tall tree, perhaps we can trust to gravity and some other simple means to bring some of it down again.

Whether fortunate or unfortunate for me in attempting to discuss this question, since it was assigned me, a most admirable book has appeared containing a long chapter full of extracts from the best recent investigators "on the theories advanced to explain the ascent of water in tall trees."[2]

The numerous theories advanced to explain the causes for the ascent of water are many of them conflicting. Few of them can here be noticed. It seems to be very generally believed that water enters the roots and root-hairs by osmotic action of the living cells. Some of the movements inside the plant can be satisfactorily explained by the changes, causing a difference of pressure (density) of the air-bubbles imprisoned in the tracheides; the water being driven from lumen to lumen in the direction of least pressure.[3]

In coniferous wood[4] the tracheides are arranged in the annual ring in radial rows, those in each radial row being nearly equal in height; tangentially, however, the rows stand at unequal heights, so that anything passing through the bordered pits (on the radial walls) from tracheide to tracheide, would go by steps spirally round the stem as up a spiral stair-

[1]Ward, pp. 116, 137.

[2]Timber and some of its Diseases, by H. Marshall Ward. Macmillan and Co., London and New York.

[3]Hartig in Ward, p. 87.

[4]Hartig in Ward, p. 88.

case. The tracheides always contain some water and some air, but the quantity varies with the season and in different parts of the tree. There is least air and most water in the tracheides of the upper part of a tree. The air is less dense in the upper parts of the tree than in the lower.

My examination of the wood of white pine very nearly confirms the spiral staircase suggested by Hartig.

With all the explanations offered for the ascent of water in a tree, the one objection which oftenest presents itself to me, is this: What prevents water from running down or back when certain forces are withdrawn. There are no series of pump valves opening in one direction only to hold all that goes above and to prevent any water from returning.

Westermair[1] advances the notion that the wood parenchyma absorbs water osmotically. The cells of this parenchyma are everywhere present and by means of numerous pits are in communication with the tracheides and vessels.

Suppose a vessel, in contact with medullary rays and wood-parenchyma at different levels. Water rises in the vessel to a given height, the level of the first medullary ray, and is held there by the pressure from below. The parenchyma at that level then uses this water as a store from which it draws by endosmose. We thus have two sets of forces, capillarity and osmosis, supplementing one another; the capillarity only *supports* the columns, the *moving* force is endosmose.[2]

Elfving points out that capillarity is effective in the lumina of tracheides and vessels, and imbibition in the solid substance of their walls, and osmotic forces are concerned in root-pressure. With these the expansion and contraction of the air bubbles must all be active in causing the movement of the water up the stem of the tree. He thinks we may safely assume that each short water-column in the series, between its two air-bubbles, exerts no pressure downwards; it is a weightless segment.

The imbibition theory of Sachs may be regarded as overthrown by subsequent researches of Vesque, Elfving, Russow, Hartig and others. Nearly all agree that osmosis accounts for the absorption of the water from the soil by the root-hairs, and for movements [3]of water in parenchyma generally. Any other theory is irreconcilable with the fact that absorption by roots is increased as the temperature of the soil rises.

[4]Godlewski decides that root pressure may sink to zero when transpiration is active; and adds we must call in the supply of energy set free by the respiration of the protoplasm, as well as turgescence, as furnishing the forces which overcome resistance to filtration, and which separate again from the dense sap in the cell.

[5]DeVries has shown that every time certain molecular decompositions occur in the cell, the attraction for water is increased; and it is extremely probable that periodic changes take place, first calling for more water, then calling for much less water and even rejecting some of it.

[1]Ward, p. 103. [2]Ward, pp. 105, 106, 107. [3]Ward, p. 117.
[4]Ward, p. 124. [5]Ward, p. 128.

With each splitting of a complex compound into simpler ones, the osmotic power of the cell is increased; while with each union of simpler into more complex molecules it is lessened; and, with every solution of a part of the protoplasm, the osmotic power increases; the reverse occurring each time an excretion of insoluble substances occurs in the cell-sap. Whence we have only to assume a certain regularity or periodicity of these processes to have all that is necessary for the hypothesis.

In conclusion, we must admit, that much remains to be learned regarding the *modus operandi* in the actual lifting process, and Mr. Ward suggests that perhaps some of the grandest results in biology may be looked for along the lines of research which shall unravel the problem of these phenomena of periodicity in root-pressure in the changes in protoplasm, its irritable movements and periodic growth.

GASES IN PLANTS. By Prof. J. C. ARTHUR, LaFayette, Ind.

[ABSTRACT.]

BRIEF historical statement of the discovery of the principal facts pertaining to the subject. The kinds and origin of gases in plants. An account of the present state of knowledge regarding the movement and distribution of gases in plants.

ABSORPTION OF FLUIDS BY PLANTS. By Prof. L. H. PAMMEL, Agricultural College, Ames, Iowa.

[ABSTRACT.]

A RÉSUMÉ on the subject of the absorption of fluids by plants, considered historically, anatomically and physiologically. Soils, absorption of water, chemical and physical absorption.

Root and root-hairs, distribution and occurrence of, on plants. How absorption is brought about. Absorption of fluids by cryptogams.

THE FLORA OF CARMEN ISLAND. By Dr. J. N. ROSE, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THIS island is situated in the Gulf of California, 120 miles south of Guaymas. The soil is very poor. On the west side is a great salt lake.

The only botanical collector who has ever visited the island is Dr. E. Palmer. He collected here in 1870 and again in 1890. During his last visit he made a complete collection of the plants of the island. The total number of species obtained was seventy, and of these six are new and seven are indigenous. Additional facts are given in the following table:

	POLYPETALÆ.	LEGUMINOSÆ.	GAMOPETALÆ.	COMPOSITÆ.	APETALÆ.	EUPHORBIACEÆ.	ENDOGENS.	GRAMINÆ.	TOTAL.
Number of species,	21	7	24	12	10	6	13	12	68
Number of genera,	21	7	21	10	8	4	10	9	60
Indigenous species,	3	2	2	0	2	2	0	0	7
New species,	3	2	1	0	2	2	0	0	6
Common to Mexico,									29
Common to Lower Cal.,									49
Common to U. S.,									16
Coll. by Palmer at LaPaz,									25

[The paper will be printed in full in Contributions from the U. S. National Herbarium.]

THE COMPOSITÆ COLLECTED BY Dr. EDWARD PALMER IN COLIMA. By Dr. J. N. ROSE, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE total number of species collected is 515, of these sixty-one are Compositæ, about 12 per cent of the whole number. The total number of species in Mexico as reported by Hemsley is 1518 of which 13 per cent are compositæ. It is surprising, however, that only ten of the sixty-one species were collected near the coast (Manzanillo) although more than half of the total number were obtained here.

Ten species or one-sixth of the whole are new species and one, perhaps two, are new genera. Many others are very rare species, some of which have not been collected for more than 100 years.

[The paper will be printed in full in Contributions from the U. S. National Herbarium.]

FURTHER OBSERVATIONS ON A BACTERIAL DISEASE OF OATS. By B. T. GALLOWAY, Washington, D. C.

[ABSTRACT.]

REVIEWS briefly the paper on this subject read at the Indianapolis meeting and then gives the results of investigations made since. The life history of the organism is set forth, it being shown, under this heading, that the germ may pass the winter on seed from diseased plants on volunteer oats and to a limited extent in the soil. The characteristics of the germ as regards its behavior on different culture media are given together with the results of inoculation experiments. Finally the experiments in combating the disease are set forth, the result of treating diseased seed with hot water, steam and various germicides being shown. The results of planting seed from unaffected regions are also set forth, also an extended series of experiments bearing on crop rotation.

RESULTS FROM RECENT INVESTIGATIONS IN PEAR BLIGHT. By M. B. WAITE, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

PEAR BLIGHT is a disease which works only in meristematic tissues. Twig blight and blossom blight explained. Methods of isolation of the microbe of blight and its cultivation on nutrient culture media. Some characteristics of the germ of blight. It is a motile *Bacillus*. Inoculation experiments with pure cultures of the Bacillus of blight. Blight in the flowers and experiments with the blight germs on pear flowers. The blight bacteria grow in the nectar and multiply there as saprophytes and then enter the tissues. The Bacillus of blight in the nectar is carried from flower to flower by insects visiting the flowers for pollen and honey. An artificial epidemic of pear blight started by infecting a few trees on the edge of an orchard and allowing free access of insects. Mosquito net bags over the flowers keep out insects, therefore protect the flowers from blight. Experiment with bees and blight germs under a tent. Trees infected with blight germs artificially may be sprayed with fungicides and the greater part of the damage prevented.

NOTES UPON BACTERIA OF CUCURBITS. By Prof. BYRON D. HALSTED, New Brunswick, N. J.

[ABSTRACT.]

MELON, squash and cucumber plants have suffered from a bacterial disease during the present year in New Jersey. The stem decays near the ground and the leaves wilt and "melt" away. Inoculations of healthy tissue were successfully made with the germs which are oval in shape. The germs when introduced into a healthy fruit by means of a flumed glass rod

quickly produce the bacterial rot. In like manner the disease can be introduced into the stems and leaves of various species of cucurbits. Squash seed for example sown in pots and the soil watered once with the fluid containing germs fail to grow. Similar seeds placed upon blotting paper under favorable conditions for growth fail when a quantity of the bacterial germs is added to the moist paper. The white seed coats soon turn brown and the embryos decay.

The same bacteria develop with rapidity in tomato fruits upon the vines and spreads through the stems of the inoculated plants. A decaying cucumber placed in a box of seedling tomatoes killed the latter in a few hours. The same germs cause a decay of the sweet potatoes with the usual exceedingly offensive odor of the rotting tubers.

A NEW NECTRIA. By Prof. BYRON D. HALSTED, New Brunswick, N. J.

[ABSTRACT.]

THE stem rot of sweet potato is a puzzling disease. As the decay begins near the surface of the ground and works in opposite directions usually several fungi are found in the affected parts. A species of fusarium is uniformly abundant upon the aërial decaying stems. Early in June an ascigerous fungus was found upon the under-ground portions of the young plants and was first thought to be a form of the black rot (*Cerato-cystis fimbriata* E. and Hals.). It, however, is a member of the genus Nectria and somewhat closely related to *Nectria Vandæ* Warh., described in *Botanische Zeitung* for 1886, as a root disease of an orchid.

The unseptate spores germinate freely in drop cultures and produced fusarium spores identical with those found in abundance upon the dead vines in the field.

The perithecia when free from all foreign matter and placed upon sterilized cylinders of sweet potato in test tubes soon produce a fine growth of fusarium followed in a few days by the young perithecia which gradually became mature. From a study of the perithecia in all their stages, the development of the organ was determined. It begins as a lateral outgrowth at right angles to the main thread which produces a number of cells like a cluster of grapes in miniature. No union of threads corresponding to a genuine act of fertilization was found.

NOTES UPON AN ANTHRACNOSE. By Prof. BYRON D. HALSTED, New Brunswick, N. J.

[ABSTRACT.]

A COLLETOTRICHUM was recently found upon *Aspidistra lurida* var. *variegata* and mostly confined to the etiolated parts. The fungus was readily propagated on sterilized petioles of Aspedistra in test tubes, also slant

agar tubes, and the dark brown bodies were uniformly developed in the germination of the spores.

Not long after a similar colletotrichum was taken upon the day lily and especially abundant upon *Funkia undulata* var. *variegata*, likewise mostly confined to the blanched portions of the foliage. Test tubes cultures were made for both these fungi and upon both hosts, all being successful. Cultures of various other plants were likewise made, as of corn, beet, lettuce. There were unmistakable differences in the fungi thus produced, demonstrating that the host must materially influence the parasite at least in the instances in question which, however, were not of plants growing under natural conditions.

ON THE PROTHALLIUM AND EMBRYO OF OSMUNDA CLAYTONIANA AND O. CINNAMOMEA. By Prof. DOUGLAS H. CAMPBELL, Palo Alto, California.

[ABSTRACT.]

1. SPORES, structure and germination.
2. Development of prothallium.
3. Structure and development of the sexual organs.
4. Fertilization.
5. The embryo; development and comparison in the two species.
6. Comparison with the development of other pteridophytes; systematic position of the Osmundaceæ.

ON THE PHYLOGENY OF THE ARCHEGONIATA. By Prof. DOUGLAS H. CAMPBELL, Palo Alto, California.

[ABSTRACT.]

1. DIFFERENT views held as to the relations of Hepaticæ and Musci to each other and to the Pteridophytes.
2. Hypothesis as to the primitive nature of the eusporangiate pteridophytes.
3. Evident inter-relationship of the different groups of the Hepaticæ.
4. Connection between thallose and foliose Hepaticæ, and between the former and the mosses.
5. Comparison of Pteridophytes and Hepaticæ.
6. Relationship of the Pteridophytes *inter se.*
7. Heterospory among the Pteridophytes.
8. Gynnosperms and Angiosperms.

ANOTHER CHAPTER IN THE HISTORY OF VENUS FLY-TRAP. By Dr. J. M. MACFARLANE, Edinburgh, Scotland.

[ABSTRACT.]

IN mechanical stimulation of leaf *two* touches are needed to cause contraction (unless stimulus be very powerful) if greater interval than one-third second elapses. If less than one-third no contraction, and a third is then needed. In first case no effect if thirty-five to forty seconds elapse between stimuli.

By repeated stimuli with intervals of forty seconds between, protoplasm becomes fatigued so that when time interval is reduced, sluggish closing is exhibited.

All parts of the lamina are sensitive to surface stimulation.

Explanation of behavior to stimulating and non-stimulating bodies to be found in tetanus of the leaf, first produced by mechanical, later by chemical stimuli.

Behavior in this respect of numerous organic and inorganic substances.

Agreement of these with Burdon Sanderson's electro-motor results.

Nature of digestive excretion.

Structure of the leaf in relation to contraction and excretion.

Perfect parallelism between combined nerve and muscular action in animals and contraction action in Dionæa.

THE FORAMINIFERA, WITH A NEW DEVICE FOR THE EXHIBITION OF SPECIMENS. By JAMES M. FLINT, Navy Department, Washington, D. C.

[ABSTRACT.]

INTRODUCING a type series of Foraminifera, consisting of 128 species selected from the deep-sea dredgings made by the U. S. Fish Commission Steamer Albatross along the Atlantic coast of N. America. A brief résumé given of the characters of the group, with some observations in support of the opinion that for the most part they pass all the stages of life at the bottom, and that but few forms, and those small and delicate, are pelagic. Modes of collection of specimens by means of the deep-sea lead, the sounding-rod and the dredge.

The series is made available for public exhibition by mounting upon a large circular disk of aluminum, securely inclosed in a box with glass top, through which projects the objective of a microscope. By simple mechanical appliances the disk is made to rotate at will, bringing the objects into the field of view.

Attention is also called to another original device for class exhibition of microscopic objects, whereby ordinary glass slides attached to an endless ribbon may be made, by a simple mechanism, to pass under the microscope without manipulation of the slides.

USES OF THE FERMENTATION TUBE IN BACTERIOLOGY WITH DEMONSTRATIONS. By Dr. THEOBALD SMITH, Department of Agriculture, Washington D. C.

[ABSTRACT.]

THE fermentation tube has been applied to bacteriological work by Miquel in 1889, and independently by the writer at about the same time (Centralblatt für Bakteriologie und Parasitenkunde, VII (1890) S. 502). The object of the paper is to call attention to its value in the differentiation of closely allied species or varieties of bacteria, in the preliminary study of gas production and in the cultivation of anaërobic forms. It is moreover useful in demonstrating in the class-room the very active metabolism of bacteria as indicated by the rapidity of gas production.

BOTANICAL FIELD WORK OF THE BOTANICAL DIVISION. By Dr. GEORGE VASEY, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE paper was an account of the field work or botanical explorations which are being conducted by the Botanical Division of the Department of Agriculture.

1. The work in Texas with a list of new species, and an account of the bulletin of Texas Flora.
2. The work in Mexico and Arizona, with an account of some species of special interest.
3. The Death Valley Expedition.
4. Special investigations in Cactaceæ.
5. Explorations in Indian Territory.
6. Explorations in Northeastern Minnesota and Wisconsin.
7. Explorations in Florida.

THE SPECTROSCOPE IN BOTANICAL STUDIES. By J. A. BRASHEAR, Allegheny, Pa.

[ABSTRACT.]

THIS paper is suggestive of a simple method of studying the selective absorption and reflection of flowers and leaves by the aid of the spectroscope. The author has made a great number of interesting studies on the colors of flowers and leaves, diagrams of a few of which will be given if desired. It is possible that the spectroscope may open a new field of research in this beautiful science.

ON THE STRUCTURE AND DIMORPHISM OF HYPOCREA TUBERIFORMIS. By GEORGE F. ATKINSON, Auburn, Ala.

[ABSTRACT.]

Hypocrea tuberiformis B. and Rav. was described from specimens collected by Ravenel in South Carolina upon stems of *Arundinaria*. The subglobose stroma only was described. A description of the perfect stage has never been published.

Ellis (Jour. Mycol., Vol. II, No. 6, p. 68), describes the perithecia from Ravenel's Fung. Am., No. 733, but states that the specimens are imperfect.

Patouillard (Bulletin de la Société Mycologique de France, Tom. VI, 2e Fascicule, pp. 107–109, 1890), describes a new genus (*Dussiella*) of *Hypocreaceæ* from specimens deposited in the Berlin Museum. These specimens were collected in Caracas and supposed to be *Hypocrea tuberiformis* B. and Rav. It is an entirely different fungus from that described by Berkeley, the perithecia being entirely immersed in the stroma, while in the American specimens the perithecia stand upon the stroma like the young horns of *Podisoma macropus*.

The conidial and perfect stages of *Hypocrea tuberiformis* B. and Rav. have been collected by the writer during the last two years in Alabama. The conidial stage appears in May upon the surface of the subglobose stroma, the conidiophores being acicular and the conidia oval or broadly fusoid. The perfect stage appears in August and September. The structure of the asci and spores resembles those of the genus *Epichlœ*, but since the stroma does not entirely embrace the host, the fungus would be placed in Saccardo's genus *Hypocrella*. The distinction, based alone on this character of the stroma, when otherwise structurally identical, does not seem sufficient ground for the separation of these forms from *Epichlœ*, but until the two genera can be monographed, *Hypocrea tuberiformis* B. and Rav. should read *Hyprocrella tuberiformis* (B. and Rav.).

ON THE REDUCTION OF THE SCAPULAR AND PELVIC ARCHES AND LIMBS IN LACERTILIA. By Prof. E. D. COPE, Philadelphia, Pa.

[ABSTRACT.]

THE reduction in the limbs as known reviewed. The places of reduced types in the system pointed out. The corresponding reductions of scapular and pelvic arches of certain genera described.

ON COLOR VARIATIONS IN CERTAIN REPTILIA. By Prof. E. D. COPE, Philadelphia, Pa.

[ABSTRACT.]

THE color variations in American Cnemidophorus species described and compared with those of *Lacerta muralis* of Europe.

The color variations of Bascanium described.
The color variations of Eutænia described.
The color variations of Ophibolus described.
Inferences and deductions.

THE FATE OF THE FUR SEAL IN AMERICAN WATERS. By WILLIAM PALMER, U. S. National Museum, Washington, D. C.

[ABSTRACT.]

A BRIEF history of the discovery of the Pribylov Islands and an account of the fur seal industry, its value and the topography and natural history of the islands.

The causes of the decrease of seal life, methods of capture and statements of the natural history of the seals bearing on the increase and decrease of the industry.

The remedy for the present condition of affairs and suggestions for future management.

To be illustrated by eighteen lantern slides, from photographs made last summer by the author, of the scenery, birds and rookeries of the islands; also by maps and specimens.

A MONOGRAPH OF THE CAROLINA PAROQUET (CONURUS CAROLINENSIS). By EDWIN M. HASBROUCK, Smithsonian Institution, Washington, D. C.

[ABSTRACT.]

COMMENCING with the early history of the species from time of first introduction to science, and following it down to present position in avifauna.

A short condensed account of its habits, and the causes which have led to its practical extermination.

An account of the former range (as illustrated by map), and the present habitat so far as known.

An enumeration of its occurrence by date in each state, showing its gradual disappearance from each, and concluding with an enumeration by decades, showing gradual receding from whole sections of the country, and where it may be found at present.

The paper was illustrated with one large map, a colored photograph of one of Maximilian's plates and specimens.

NOTES ON THE PHYSIOLOGY AND STRUCTURAL CHANGES IN CAYUGA LAKE LAMPREYS. By SIMON H. GAGE, Ithaca, N. Y.

[ABSTRACT.]

THE specific characters of the forms inhabiting Cayuga Lake are given and it is shown that two genera and two species are represented; one being a land-locked form of the sea lamprey (*Petromyzon marinus*), the other the brook lamprey (*Ammocœtes Petromyzon branchialis*).

It is shown that there are profound structural changes occurring in the alimentary canal and fins in both species during the breeding season.

The structural changes in the generative organs of the male and female sea lamprey are figured and discussed.

The food of the adult sea lamprey is shown to be blood and its transformation in the alimentary canal is discussed.

THE TRANSFORMATIONS OF THE VERMILION-SPOTTED NEWT (DIEMYCTYLUS VIRIDESCENS). By Prof. SIMON H. GAGE, Ithaca, N. Y.

[ABSTRACT.]

IT is shown that this batrachian presents three distinct forms in its life cycle: (*a*) an aquatic, branchiate form; (*b*) a red, purely terrestrial, air-breathing form; and (*c*) an adult viridescent form, which is by choice aquatic, but may live for more than a year out of the water.

After becoming adult and transforming into the viridescent form, it always remains of that general coloration whether it lives in water or on land, thus showing that neither food, season nor environment gives rise to the coloration, but that it is normal for a definite phase or period of life.

The character of the oral epithelium seems directly dependent on the mode of respiration, being stratified and non-ciliated with an aquatic or mixed respiration and being columnar and ciliated with aërial respiration.

ON THE EJECTION OF BLOOD FROM THE EYES OF HORNED TOADS, PHRYNOSOMA. By Prof. O. P. HAY, Irvington, Ind.

[ABSTRACT.]

GIVES the results of some experiments with *Phrynosoma coronatum* from California. A considerable quantity of a red fluid was thrown out from the eye, and a microscopical examination proved it to be blood.

ON THE TURTLES OF THE GENUS MALACLEMYS. By Prof. O. P. HAY, Irvington, Ind.

[ABSTRACT.]

THE paper discusses briefly the characters of the genus Malaclemys among turtles, and some points in the nomenclature of some of the species. Considers also the relative size of males and females, and the food of some of the species.

THE NEW ZEALAND FISH FAUNA. By Prof. THEODORE GILL, Smithsonian Institution, Washington, D. C.

[ABSTRACT.]

OVER two hundred and thirty fishes are now known as inhabitants of the salt and fresh waters of New Zealand. These represent various families peculiar to the southern hemisphere, some families common to temperate waters and a few mostly confined to the tropicopolitan area. New Zealand is a zoogeographical region distinct from the Australian.

[This paper will be printed in Memoirs Nat. Acad. Sci.]

THE PERSISTENCE AND RELATIONS OF FAUNAL REALMS. By Prof. THEODORE GILL, Smithsonian Institution, Washington, D. C.

[ABSTRACT.]

THE primary zoogeographical divisions or realms of the globe are radically distinguishable into the *inland*, including land and fresh-water animals, and *marine*. Temperature is the prime factor in the limitation of the marine faunas, but has been subordinated to others in the distribution of the inland animals. Those other factors are the isolation of the regions inhabited by them without possibility of passing from one into the other and the progressive evolution of species. The length of time that isolation has persisted is testified to by the development of many families peculiar to the inland faunas. Especially notable is the development of the plectospondylous and nematognathous fishes and their ramification into many families various ones of which are characteristic of special regions. The segregation of the respective families indicates two great centres or regions of distribution: (1) an *Eogean*, including the Australian, South American and African realms; (2) a *Cenogean*, embracing the Indian, Eurasiatic and North American realms.

THE NATIONAL ZOOLOGICAL PARK. By Dr. FRANK BAKER, 1315 Corcoran street, Washington, D. C.

[ABSTRACT.]

A STATEMENT of the history and present condition of the National Zoological Park. Illustrated by a model.

THE PRESENT CONDITION OF THE STUDY OF DEEP-SEA FISHES. By Prof. G. BROWN GOODE and TARLETON H. BEAN, U. S. National Museum, Washington, D. C.

[ABSTRACT.]

THE study of deep-sea fishes has only become possible within the past few years. No department of zoology has profited more by recent deep-sea explorations than ichthyology. Risso, as early as 1826, called attention to the fauna of the great depths, but his views were neglected and have only recently been recalled to memory. Lowe of Madeira, was also a pioneer from 1843 to 1874 in the study of deep-sea fishes. Günther, in 1864, extended the generalization of Risso. The study is still in its infancy, yet a very good general idea of the peculiar fauna has been attained. The distribution of forms in the abysses is very peculiar and as yet not well understood. Gill's "Bassalian Realm" has real existence. The abyssal fishes have many marked peculiarities. There are, however, many forms which may belong to either surface or abyss. Agassiz in his recent Galapagos expedition has gathered much new material for the study of mid-strata. The American work on deep-sea fishing is all that is now in progress; the English, French, Italian and Scandinavian having been long since discontinued.

THE MOUTH OF COPRIS CAROLINA AND NOTES ON THE HOMOLOGY OF THE MANDIBLE. By Dr. JOHN B. SMITH, New Brunswick, N. J.

[ABSTRACT.]

COPRIS CAROLINA is the largest of our eastern "Tumble-bugs." Its food consists of excrementitious matter, usually in a rather soft or semi-liquid condition, and yet the taste organs, or what are assumed to be such, are enormously developed. The mandibles in an insect of these habits are comparatively useless, and are incompletely developed, partly membraneous. In many others of the Lamellicorn series the mandibles are imperfect, and the parts of which they are composed and their homologies are easily studied. All the parts of the maxilla have been identified in the labium which always has at least one pair of sclerites united. It is known that the mandibles are sometimes composed of more than one sclerite, but they have not been named nor have they been homologized with the maxillary sclerites. In *Copris* we find this structure:—At the base a large corneous sclerite furnishing attachments for tendons and muscles and this may be called the *basalis* or basal piece. There is in some species another small sclerite attached at the base, which represents the *cardo*, and which I call the tendon bearer from its function. The *basalis* is homologous to the stipes. Another of the basal pieces I call the grinder or *molar*, and this I believe to be homologous with the subgalea of the maxilla. Its function is expressed by its name. All the food passes between these grinders. They are asymmetrical, one concave, the other convex. They

vary much in prominence in different species. Between this subgalear piece, which is well chitinized, and a flattened, more membraneous piece attached to the basalis, is a small sclerite, which I call the *conjunctivus* or connecting piece. The flat, membraneous piece forming most of the inner portion of the mandible, is the homologue of the galea, and similar to it in function. I call it the *terebra* or piercer, as, when it is chitinized, it forms the apical or sickle-shaped tooth of the mandible. It is variably distinct, sometimes entirely separate from all other parts of the organ. Arising from the same base as the *terebra* is another small membraneous piece, the *prostheca* of Kirby. The piece is homologous with the *lacinia* and I would prefer to call it a *penicillus* or brush, from its function. This piece forms the median or second tooth of the mandible, and even in highly chitinized forms, *e. g.*, *Passalus*, is sometimes movable.

The *epipharynx* is greatly developed in *Copris*. It lies in the cavity under the outer covering of the head, and forms the roof of the mouth. It is chitinous, fringed with fine hair at the edges and set with short, stout, movable spines inwardly. Through the centre is a chitinous loop, more densely set with spines. Its paired character is more obvious in *Cetonia*. The spines are movable but seem not to be glandular.

The ligula are behind the palpi, separated at base, but united with the prominent paraglossæ. The ligula itself is set with fine soft hair, making it velvety in appearance. Between these pieces and guarding the entrance to the mouth is a toothed structure at the base of a membraneous or muscular structure which closes the mouth opening. These teeth are not movable, nor are the bases to which they are attached. I cannot find any described organ with which they agree, and have seen too few forms to risk naming them.

NOTES ON THE HOMOLOGY OF THE HEMIPTEROUS MOUTH. By JOHN B. SMITH, Sc.D., New Brunswick, N. J.

[ABSTRACT.]

THE mouth parts of the Hemiptera as usually explained are, a beak or rostrum, composed of the labium and grown together labial palpi, and four slender bristles, representing the elongated mandibles and maxillæ. The maxillary palpi are wanting. Careful study of dissections of *Cicada* and *Belostoma* mouth parts shows that this is erroneous. Seen from the side, four distinct sclerites are remarked: the labrum, the mandibles, the maxilla and the beak. The mandibles are not elongated; they are small, not functional and in Cicada are distinct, lying close to the inner margin of the labrum, the points acute and diverging at tip. The labrum is convex outwardly and on the inside is a salivary gland leading by a duct through the pointed prolongation into the beak. This supplies the irritating liquid, causing the severe pain of some bug-bites. The two elongated bristles are maxillary structures, and at their side the maxillary palpi are

distinct in *Cicada*. The maxillary parts represented in the two pairs of bristles are the lacinia and the stipes. They arise close together from a winged, semi-membranous process and are of nearly equal length. The beak is four jointed, the basal joint quite usually short and apparently forming part of the head structures. My studies in the Diptera lead me to believe that this structure is maxillary rather than labial, the joints representing the cardo, the subgalea and the two-jointed galea. This would bring the structure into accord with what is observed in the Diptera, and accounts for all the maxillary structures. It leaves the labial parts entirely unrepresented, and I believe them to be unrepresented in the species studied by me. The mentum is represented by a boat-shaped structure between the processes, giving rise to the maxillary bristles. I have found no processes arising from it. In some species the epipharynx is noticeable, as a process arising from the labrum, and furnished on the inner side with fine dense hair, giving the surface a plush-like appearance.

EPIPHARYNX AND HYPOPHARYNX OF ODONATA. By Dr. JOHN B. SMITH, New Brunswick, N. J.

[ABSTRACT.]

THE *Epipharynx* is attached to the underside of the labrum, is membraneous in texture, and is set with rounded tubercles, not bearing hair, but with a round opening in the crown and through the centre. These tubercles are set very regularly in a series of semicircles.

The *Hypopharynx* is attached to the ligula, and indeed ligula and hypopharynx are largely combined. It is somewhat bladder-like, quite prominent, irregularly set with tubercles similar to those on the epipharynx; but each is furnished with a long stout hair, evidently hollow to the tip, but without external opening that could be discovered. Within the bladder-like expansion is a glandular structure from which a duct leads to a chitin-margined opening. This is covered by another membraneous expansion, set with somewhat differently formed tubercles and surmounted by chitinous spine-processes, which are not real hairs, although at first sight they look like it. They are really canula, open at one side, carrying the secretion of the gland already referred to. The labial development is at first sight similar to that in some *Hymenoptera;* but the covering of glandular and canulate hairs is quite unlike anything I have seen elsewhere, and is indicative of a function which is not tactile or gustatory only.

MICRO-ORGANISMS AS INSECTICIDES. By Prof. C. V. RILEY, U. S. Entomologist, Washington, D. C.

[ABSTRACT.]

DISCUSSES the various attempts to use and control micro-organisms for the destruction of insects injurious to vegetation. Refers particularly

to the work of Professor Snow of Kansas in his efforts to destroy the chinch bug by these means, and points out the difficulties of the situation and the danger of erroneous conclusions being drawn.

PARASITISM IN COLEOPTERA; IN DIPTERA; AND IN BRACONIDAE AND ICHNEUMONIDAE AMONG HYMENOPTERA. By Prof. C. V. RILEY, U. S. Entomologist, Washington, D. C.

[ABSTRACT.]

DISCUSSES the nature of parasitism in the orders and families mentioned, its effect on both the adolescent and adult states and the structural consequences.

ON THE HABITS OF THE PROCTOTRYPIDÆ. By WM. H. ASHMEAD, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

COMPARES the Proctotrypidæ with the Chalcididæ, the position they occupy in a systematic arrangement of the families of the Hymenoptera, and gives a résumé of the habits of groups, genera and species.

MODIFICATION OF HABIT IN PAPER-MAKING WASP. By Miss MARY E. MURTFELDT, Kirkwood, Mo.

[ABSTRACT.]

THIS observation refers to a recently discovered habit of *Polistes rubiginosus* of making use, in the building of its cells, of fibres torn from the paper bags employed for the preservation of grapes against fungous diseases.

ABNORMAL BEES. By Prof. A. J. COOK, Agricultural College, Mich.

[ABSTRACT.]

SEVERAL cases of one-eyed bees are described. The single eye is crescent-shaped and situated centrally, high up on the epicranium. The bees are workers, and otherwise normal, except the ocelli are absent.

Several white-eyed drones, all from a single queen, are described. The ocelli are also white.

Several so-called hermaphrodites, some drones and some workers, are described. The combinations of drone and worker characters are very varied. In one case, one entire side is drone and the other worker.

The paper was illustrated by diagrams.

[This paper will be printed in Gleanings in Bee Culture and Michigan Agricultural Report.]

ENEMIES OF THE HONEY BEE. By Prof. A. J. COOK, Agricultural College Mich.

[ABSTRACT.]

THE various enemies of the honey bee in the United States, from mammals to the fungoid germs or bacilli are named and their mode of attack and effect are given. The enemies consist of mammals, birds, batrachians, several species of insects belonging to nearly all the orders, species of all orders of Arachnida, and species of Asclepias and two species of Bacilli.

[This paper will be printed in American Bee Journal and Michigan Agricultural Report.]

ON THE KINDS OF MOTION OF THE ULTIMATE UNITS OF CONTRACTILE LIVING MATTER. By Dr. JOHN A. RYDER, University of Penn., Philadelphia, Pa.

[ABSTRACT.]

1. AMŒBA has a vortex movement of its particles; axes infinite in number; vortex flattened or elliptical, due to gravity, cohesion, etc.

2. Muscle has no such obvious vortex movement of its particles or inotagmata (Engelmann), but all move with their axes parallel to the surface of the muscle; they therefore have definite axes, as have all the subsequent classes.

3. In the flat cilium there may be alternating rhythmical movement of the inotagmata of opposite sides.

4. In the stalk of Vorticella, the inotagmata are arranged in whorls or superposed disks. The inotagmata of one side of those disks have a maximum motion; those of the opposite side a minimum movement. The points of maximum and minimum motion of the inotagmata in the superposed disks in the stalk of *Vorticella* form two spiral lines. This effects the spiral contraction of the stalk of this organism since the points where the maximum and minimum motion of the inotagmata occur are fixed.

5. In certain flagella and organisms the inotagmata are arranged as in 4, but their points of maximum and minimum motion can revolve around the centre of the column of plasma of which they form a part, either to the right or left hand thus propagating a spiral or screw-like motion forwards or backwards.

ORIGIN AND DEVELOPMENT OF PARASITIC HABIT IN MALLOPHAGA AND PEDICULIDÆ. By Prof. HERBERT OSBORN, Ames, Iowa.

[ABSTRACT.]

DISCUSSES present position of Mallophaga, the essential structural characters and their modification as a result of parasitism especially as compared with related non-parasitic forms.

Attention is also called to the similar modifications in the parasitic group *Pediculidæ*.

THE ORIGIN AND DEVELOPMENT OF PARASITISM AMONG THE SARCOPTIDÆ. By H. GARMAN, Lexington, Ky.

[ABSTRACT.]

EVOLUTION of the group Sarcoptidæ. Comparison with related forms and detailed discussion of examples of the group.

THE BIOLOGY OF THE CHALCIDIDÆ. By L. O. HOWARD, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

A GENERAL consideration of the biology of the Chalcididæ to form a part of a symposium upon parasitic insects.

ON THE IMPORTANCE OF A TABLE AT THE NAPLES STATION. By CHARLES W. STILES, Washington, D. C.

[ABSTRACT.]

THIS paper will present the importance of a table at the International station for Zoölogical research at Naples and the work that has been thus far accomplished.

[A committee was appointed by the Council to secure an American table at the station.]

ON A NEW EDITION OF THE NOMENCLATOR ZOOLOGICUS. By LEONHARD STEJNEGER, Smithsonian Institution, Washington, D. C.

[ABSTRACT.]

THE work of compiling a new edition of the Nomenclator Zoologicus having become an undertaking of such a magnitude as to be beyond the power of any private individual, the Smithsonian Institution was induced to take it up. The present writer was appointed editor, Mr. S. H. Scudder having declined to undertake it.

It is estimated that the new decennial supplement will contain over 15,000 generic names proposed between 1879 and 1889, with the addition of such names not included in the previous editions which may be encountered before the volume goes to press. It is the intention to follow this one up by another in 1900, both to be included in the "Universal Index" then to be issued. The present editor will continue as such, so that the publication of the Index may not be unduly delayed.

Zoölogists are cordially invited to coöperate by sending in lists of generic names proposed between 1879 and 1889, or not found in the previous editions.

A NOVEL COLOR-ILLUSION AND A NEW METHOD OF COLOR MIXTURE. By Prof. JOSEPH JASTROW, University of Wisconsin, Madison, Wis.

[ABSTRACT.]

THE methods were described by use of apparatus.

A CASE OF THE LOSS OF SENSE OF SMELL. By Prof. JOSEPH JASTROW, University of Wisconsin, Madison, Wis.

[ABSTRACT.]

AN account of experiments showing extent of loss and its relation to smell.

SECTION H.

ANTHROPOLOGY.

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ADDRESS

BY

JOSEPH JASTROW,

VICE-PRESIDENT, SECTION H.

THE NATURAL HISTORY OF ANALOGY.

The progress of modern science is dependent largely upon the wise direction of two types of intellectual effort; first, the collection and orderly arrangement of facts; second, the framing upon the basis of the facts of significant generalizations and suggestive theories. The importance of resting firmly upon the facts, of avoiding premature and ambitious generalizations, of minimizing the effects of personal bias is universally admitted, and finds practical realization in the trained skill and costly apparatus devoted to extending our powers of observing facts. The mere gathering of facts, however, runs the risk of becoming a routine and unthinking task, lacking the enlivening and unifying interest of some general body of doctrine. Theories tell us where to look for facts and how to judge their importance. The discoverer of a fact is not often he upon whose senses the novel phenomenon was first impressed, but rather the one who realizes the import of the observation.

Our Association recognizes the importance of these two types of work by devoting the proceedings of the sections to the description of new facts and new methods of obtaining them, while in the vice-presidential and other addresses it gives opportunity for the treatment of the more general problems of the day. It has been the custom of this section to expect from its presiding officer

the treatment of some question arising directly from his special studies and interests. Following this precedent I should have spoken to you of some of the many lines of advance along which modern psychology is now so rapidly progressing, and in so doing I should have embraced the very welcome opportunity of illustrating the importance to the students of anthropology, of the results gained in the modern psychological laboratory. On the other hand I feared the danger of the necessarily technical treatment of so special a topic, and decided that I was equally likely to accomplish my two main objects with perhaps less danger of an uninterested audience, by selecting a theme of closer interests to the students of man. My one object is to emphasize the importance of the field of study common to anthropology and psychology; the other to illustrate the applicability of scientific methods to the elucidation of problems in these fields. I have accordingly announced my subject as the Natural History of Analogy, and wish to suggest by this title the treatment, according to the methods of natural science, of a type of mental action, interesting at once as a psychological process and again from its practical results as a factor in the anthropological history of the race. I shall describe my genus, indicate the extent and variety of its occurrence, the part it plays in the economy of nature, the general laws which it illustrates, and the train of thoughts to which these considerations give rise. And this treatment of my topic is offered as a contribution to the science of anthropological psychology, a department dealing with the mental traits of primitive man whose relics we collect in our museums; of the lower grades and races of men whom we send explorers to study; and with the survival and transformation of these primitive customs and beliefs in the history of culture.

An analogy is a kind of reasoning, and as such is referred to the logician for more precise definition. His briefest explanation of the term would perhaps be the inference of a further degree of resemblance from a given degree of resemblance, the argument that because the Earth and Mars agree in the possession of a solid crust, an atmosphere, presence of water, changes of seasons, the possibilities of rain and snow, and other observed qualities they will also agree in the further respect of being inhabited. While regarding this as the exemplar of what we should mean by the term, I will apply the name to forms of thought diverging more or less from, though closely related to this ideal.

We recognize as the basis of this inference a belief in some connection underlying the resemblance. This belief may be neither distinct nor formulated, and while unconsciously felt and barely expressible, is communicated to others and becomes an influential factor in the fixation of belief and the guidance of conduct. Logically, analogy is always a weak argument and becomes weaker, as the range of observed resemblance is more and more limited, as these resemblances belong to accidental, unessential traits, and as the underlying basis of the inference is removed from direct verification. The relation of logic to psychology, however, is very much that of how we ought to think to how we do think; the logician is the gardener bent upon training certain selected flowers according to an ideal standard, and discarding all others as weeds: while the psychologist is the botanist to whom all plants, weeds and flowers alike, are worthy objects of study and who, indeed, traces significant resemblances between the despised weed and the choice flower.

My object will be to trace through the less advanced stages of human development, the evolution of this form of thought, which scientists to-day use only with the greatest caution, and to which they assign but a limited and corroborative value; and it will appear that this form of thought is dominant in primitive types of mind, that it has an important anthropological history, and has left its unmistakable impress upon many phenomena of our civilization, marked as obsolete perhaps in the dictionary of the cultured, but current still in the parlance of the average man and woman.

. . . . . .

The great law of apperception teaching that we observe according to our inherited and acquired faculties, that we in a very real sense create the world in which we live, explains the difficulty of realizing modes of thought strikingly different from our own, either as more primitive, more complex, or as based upon other perspectives of the social, intellectual and ethical rules of conduct. To the supremely civilized citizen of the nineteenth century, the mental life of one who has hardly a firm hold on the first round in the ladder of civilization is naturally somewhat incomprehensible. The best we can do is to contrast a few of the most conspicuous thought habits in the primitive and in the cultured man, and thus suggest the direction and the nature of the evolution of the one from the other. Prominent among such contrasts is the different

standings occupied by the facts and reasonings of science in primitive and in highly civilized life; and an important part of this difference may be viewed as the shifting of the position occupied by the argument by analogy. Deeper than the language of words and underlying their use and formation is the habit of comparing object with object, of tracing resemblances and noting contrasts. It would seem that in the savage's use of this process there is lacking the distinction between the resemblances inherent in the objects and those originating in the mode of viewing them; subject and object are still merged in a vaguer realm of thought where myth and science, poetical fiction and evident fact mingle without let or hindrance. Roughly speaking, the savage frames his world by the realization of his simple fancies suggested by slight analogies where the man of culture examines the objective causes of phenomena under the guidance of scientifically established principles and accurate logic. Fortunately, however, for our power of realizing bygone mental traits these forms of belief still find currency as survivals in Mr. Tylor's apt words "of the lower culture which they are of to the higher culture which they are in." We thus can understand the belief we no longer share; we can appreciate as suggestive myth or far-fetched analogy what to our ancestors may have been a plausible belief or a satisfactory explanation.

I will now illustrate by a few examples selected from an almost endless field the role that analogy plays in primitive circles, the essential influence it exerts over thoughts and customs in the early history of mankind. Take first that widespread class of customs and observances by which the savage regards himself as influencing for good or ill the fate of friend or foe. The Zulu chewing a bit of wood to soften the heart of the man he wants to buy oxen from, or the woman he is wooing (Tylor); the Illinois Indians making figures of those whose days they desire to shorten and stabbing these images to the heart, or by performing incantations upon a stone trying to form a stone in the hearts of their enemies (Dorman); the Peruvian sorcerer, making rag dolls and piercing them with cactus-thorns, and hiding them about the beds to cripple people; or the native of Borneo, making a wax figure of his enemy in the belief that as the image melts the enemy's body will waste away (Tylor); bewitching by operating upon a lock of hair or the parings of the finger nails and the consequent widespread custom of religiously preventing such personal scraps from falling

into others' possession;—all these varied forms of primitive witchcraft rest upon the notion that one kind of connection, one link of resemblance will bring with it others. The argument if explicitly stated, as can hardly be done without doing violence to its instructive force, would perhaps read thus: this bit of wood or stone resembles this man or woman in that the one represents the other; therefore they will further resemble one another in that whatever will make the one soft and yielding or the other hard and unfeeling will have the same effect on the other. This is seldom the whole argument but it is a factor in the fixation of the belief.

Resting upon a similarly indirect argument by analogy we find another series of primitive beliefs according to which the partaking of any portion of an animal will endow the partaker with the typical qualities of the animal. When the Malays eat tiger to acquire the sagacity as well as the cunning of that animal, the Dyaks refuse to eat deer for fear of becoming faint-hearted, the Caribs eschew pigs and tortoises for fear of having their eyes grow small (Lubbock); when we find in an ancient Mexican rite, called the eating of the God, an elaborated and symbolical form of the same belief, and when we trace similar observances through all stages of culture, we can appreciate how widespread is the use of the argument by analogy and how essentially similar are its effects in widely separated communities.

The use of omens, the interpretations of signs and coincidences form another rich field for illustration of arguments by analogy. "Magical arts," says Mr. Tylor, "in which the connexion is that of mere analogy or symbolism, are endlessly numerous throughout the course of civilization. Their common theory may be readily made out from a few typical cases, and thence applied confidently to the general mass. The Australian will observe the track of an insect near a grave to ascertain the direction where the sorcerer is to be found by whose craft the man died. . . . The Khondi sets up the iron arrow of the War God in a basket of rice and judges from its standing upright that war must be kept up also, or from its falling that the quarrel may be let fall too; and when he tortures human victims sacrificed to the earth goddess he rejoices to see them shed plentiful tears which betokens copious showers to fall upon his land." "In the burial ceremonies of the natives of Alaska if too many tears were shed they said that the road of the dead would be muddy, but a few tears just laid the dust." (Dor-

man.) "The Zapotecs had a very curious manner of selecting a manitou for a child at its birth. When a woman was about to be delivered, the relatives assembled in the hut and commenced to draw on the floor figures of different animals, rubbing out each one as fast as completed. The one that remained at the time of the birth was called the child's second self and as soon as grown up he procured the animal, and believed his health and existence bound up with it." (Dorman.) The taking of omens by the flights of birds or the tracks of animals, by the sky, by the inspection of sacrificed animals, by the trivial happenings of daily life, abound in savage life and in a fair proportion of cases carry with them the original ground of their origin that saves them from being mere caprice. And in all those endless appeals to chance or lots for the detection of crime, the unfoldment of the future, the prediction of the issues of disease, or of important tribal events, there is always some underlying link of connection between the kind of omen or the nature of its interpretation and the issue it signifies, and this connection it is, however slight or fanciful, that maintains the belief in the further bond of omen and issue.

There is one further variety of omens in which analogy finds ready application, the ancient and still current practice of dream interpretation. The more systematic forms of this to be treated further on are perhaps more instructive, but the principles underlying them are the same in the most superstitious savage, in the toiling mystic of the middle ages and in the science veneered charlatan of to-day.

That these connections of cause and effect may travel still further along the path of analogy without losing force, is well illustrated in the observances regarding the use of names. The connection seems to pass from thing to image, to name, much as picture writing passes into word-writing. The use of idols is abundant evidence of the extent of this mental operation; what is done to or for the idol is analogically transferred to the god, and the confusion may become so gross that when the oracles of two gods disagree, their idols are knocked against each other and the one that breaks is declared in the wrong. A drawing or other rough resemblance may do service for the thing, especially in sacrifices of objects of value. By similar steps the name becomes an essential portion of the object or person named and analogies formed through the name are applied to the thing. Thus a man may be bewitched through his

name; hence the name is not uttered and we have the taboo in its various forms. In Borneo the name of a sickly child is changed to deceive the evil spirits that torment it. The Mohawk chief can confer no higher honor on his visitor than by giving him his name, with which goes the right of regarding the chief's fame and deeds of valor as his own. When totem and tribal names are assumed to obtain the qualities of the animal namesake, or the reverence due to the person is transferred to the name, and when incantations and the utterances of mystic formulæ are granted like efficacy as the operation with things, we see the operation of the mental law under discussion; though it is still more aptly illustrated in the more artificialized practices of the Chinese physician, who for lack of a desired drug will "write the prescription on a piece of paper and let the sick man swallow its ashes or an infusion of the writing in water," or of the Moslem who expects relief from a decoction in which a verse of the Koran written on paper has been washed. (Tylor.)

It is practically impossible to exhaust the various lines of thought along which the argument by analogy has been operative in aiding the formation of primitive custom and belief, and I must conclude my summary with the mention of two types of the argument somewhat more general than those already instanced. I have all along tried to avoid the confusion between analogy and simple metaphor or simile. When we speak of a head of cabbage, the trunk of a tree, or the legs of a table, we understand that we have applied these names on the basis of resemblances to objects to which the names more strictly belong, but when the Chinese doctor administers the heads, middles and roots of plants, for the heads, bodies and legs of his patients respectively, he is clearly led to do so by a vague sense of analogical fitness. This kind of reasoning abounds in primitive ceremonials, the appropriateness of the observances and the elements of the ritual depending upon resemblances, or symbolical suggestiveness. It is difficult to find instances of this trait in which a more or less conscious symbolism is excluded, for we know how readily the savage mind, in the somewhat more developed stages, uses this mode of thought, as is evidenced by the ingenuity of their picture writing, gesture language and tribal signals. We thus reach such general principles as that unusual phenomena have unusual significance, and that to accomplish important objects, drastic means and rare substances must be em-

ployed. Things will be effective according to their divergence from the usual and the common experience of mankind. The bizarre fancies and grotesque performances of savages in part derive their character from the application of this principle. The reverence shown to the belongings of the white man and the curious uses to which they are put by savages are also cases in point. In their ritual observances as well as in medical practice the same principle is involved. One illustration will perhaps suffice to recall this familiar mode of thought. Dorman cites the fate of an Indian warrior brought to camp after a most disastrous encounter with a grizzly bear. To repair his very serious injuries "the doctor compounded a medicine that really ought to have worked wonders. It was made by boiling together a collection of miscellaneous weeds, a handful of chewing tobacco, the heads of four rattlesnakes, and a select assortment of worn-out moccasins. The decoction thus obtained was seasoned with a little crude petroleum and a large quantity of red pepper, and the patient was directed to take a pint of the mixture every half hour. He was a brave man, conspicuous for his fortitude under suffering, but after taking his first dose he turned over and died with the utmost expedition."

Another very general train of thought was perhaps suggested by the failure of the ordinary omens, and thus the principle was reached that the analogy proceeds not according to resemblance but by contrast. To take another illustration from Mr. Tylor: the Zulus when dreaming "of a sick man that he is dead, ... say 'because we have dreamt of his death he will not die.' But if they dream of a wedding dance it is the sign of a funeral. So the Maoris hold that a kinsman dreamt of as dying will recover, but to see him well is a sign of death. Both races thus worked out by the same crooked logic that guided our own ancestors, the axiom that dreams go by contraries."

Postponing for later discussion the more important of the considerations to which these illustrations of primitive thought habits give rise, I will pass to another species of the analogical family, the use of analogy among children, and thus connect the traits typical of the childhood of the race with those distinctive of the childhood of the individual.

That children are fond of reasoning by analogy there can be no doubt; their confusion of fact with fancy; their lack of scientific knowledge and the ability to refer effects to proper causes, their

great love for sound effects and play of words, the earnestness of their play convictions—all these furnish a rich soil for the growth of such habits of thought as we are now considering. On the other hand the influence of their adult companions, of their civilized surroundings, of the growth of the make-believe sentiment by which the laws of the real world are differentiated from those of fairy-land make it difficult to pronounce as an argument by analogy what may really be a half-conscious play of fancy or jugglery of words and ideas. When I admit that I found extreme difficulty in collecting even passable arguments by analogy in children, I must accompany the admission with the conviction that the difficulty is due to the absence of good collections of children's original and typical sayings and doings. What fond parents are apt to observe and newspaper paragraphers to record are sayings that amuse by a quaintness or their assumption of a worldly wisdom beyond their years, while the truly suggestive traits pass unrecorded for lack of psychologically informed observers. The little boy who, when asked his age, said he was nine when he stood on his feet but six when he stood on his head, because an inverted 9 makes a 6, was certainly reasoning by analogy, however little faith he may have had in the correctness of his reasoning. The children who believe that butter comes from butterflies, and grass from grasshoppers, beans from bees, and kittens from pussy-willows (Stanley Hall) may be simply misled by sound analogies, but when Sir John Lubbock tells us of a little girl saying to her brother, "If you eat so much goose you will be quite silly," and adds that, "there are perhaps few children to whom the induction would not seem perfectly legitimate," we appreciate that such arguments, so closely paralleling the superstitions of savages may be more real to children than we suspect.

I will now enter in my search for reasonings by analogy upon a field of greatest interest to the student of the history of culture; namely, in the household traditions, the superstitions, and the pseudo-scientific systems, that originated among our ancestors remote or immediate and are still far from obsolete in all but the upper strata of our civilization. This portion of my theme indeed presents an *embarras des richesses* and the illustrations I will cite form but an insignificant share of those that could readily be collected. Certainly more than one volume of the history of human error would be devoted to those due to an unwarranted use of the argument by analogy.

In order to have the kind of illustration of which we are in search clearly in mind, let us take a flying excursion into that general body of superstitions and folk-lore customs which no nation however high or low in the scale of civilization is without. The widespread custom of carrying baby upstairs before being taken to the lower floors of the house, so that he may be successful in life and participate in its ups rather than its downs, rests upon baby-logic indeed. The belief that if baby keeps his fists tightly closed he will be stingy, but if he holds an open palm he will be generous, likewise requires no interpretation. It is forbidden, too, to measure a child, for measuring it is measuring it for its coffin. To the German peasant if a dog howls looking downward it means death, if upward recovery from sickness. "The Hessian lad thinks that he may escape the conscription by carrying a baby-girl's cap in his pocket,—a symbolic way of repudiating manhood." "Fish," says the Cornishman, "should be eaten from the tail to the head, to bring other fishes' heads towards the shore, for eating them the wrong way turns them from the coast." "It is still plain," says Mr. Tylor, from whom I have cited some of these examples, "why the omen of the crow should be different on the right or left hand, why a vulture should mean rapacity; a stork, concord; a pelican, piety; an ass, labour; why the fierce, conquering wolf should be a good omen, and the timid hare a bad one, why bees, types of an obedient nation, should be lucky to a king, while flies returning however often they are driven off should be signs of importunity and impudence. And as parallels to these signs in the vegetable world one may cite the amaranth as signifying immortality; ivy, strength; cypress, woe; heliotrope, attachment; aspen, fear; aloes, bitterness; while through more artificial associations the laurel becomes the sign of renown; the rose, of love; the olive, of peace; and the palm, of victory.

Instead of continuing this citation of instances taken from various fields, I will group my selections about a few topics. For the rest of my citations I will go to a few selected topics: first, to the analogies underlying dream interpretation, then to analogies connected with names and numbers, next to those underlying the practices of folk medicine; and as types of the pseudo-sciences in which analogies are systematized and elaborated, I will consider the doctrines of sympathy, of signatures, of astrology and kindred sciences.

To run through the vast literature of dream interpretation, reviewing the various phases it presents throughout the history of

culture, tracing the successive additions and modifications it underwent, would certainly be an interesting task to one with patient devotion to the bypaths of human history; among the results of such a review would be a rich harvest of arguments by analogy. I prefer, however, to limit my excursions into this field to a survey of the most modern representatives of this ancient science, the cheap dream books that are doubtless for sale in every American town. My selections from this literature have been made with a view of presenting the typical kinds of analogy through which modern dream omens are believed in and this kind of literature finds a sale. "To dream of using glue," one of the authorities tells us, "foretells imprisonment for yourself or friend," and this because a prison and glue are alike in that it is difficult to be released from the hold of either. Similarly, because the pineapple has a rough and forbidding appearance it becomes in dreams the omen of "crosses and troubles." This seems hardly more than a play of words; indeed we have here touched one of the many points where metaphor and analogy meet. For instance, we commonly speak of the ladder of success and the ups and downs of fortune; the dream book tells us that, "to dream of going up a ladder foretells the possession of wealth, coming down, of poverty." The common phrase of "mud slinging" is thus interpreted by the dream-books, "to dream of dirty dirt or mud signifies that some one will speak ill of you. If some one throws dirt on you it foretells that you will be abused." To the same category belong the dream-book maxims, that "to dream of being mounted on stilts denotes that you are puffed up with vain pride;" to dream that you gather fruit from a very old tree is generally supposed to prognosticate that you will succeed to the wealth of some ancient person; if you dream of a clock and the hands stop it means death, if the hands keep moving, recovery;" "to dream of a concert means a life of harmony with one you love." So, too, various objects become significant of their striking characteristics: the earthworm from its habits of underground and secret destruction denotes "secret enemies that endeavor to ruin and destroy us," and all strongly redolent food such as onions, garlic and leek, easily betraying the one who has partaken of them becomes indicative of the betrayal of secrets and the like. Mr. Dyer cites some apt lines in which the logic is about as meritorious as the verse:

" To dream of eating onions means
Much strife in thy domestic scenes.
Secrets found out or else betrayed
And many falsehoods made and said. "

Mr. Tylor has made a collection of dream omens of similar character: "to wash the hands denotes release from anxieties;" "to have one's feet cut off prevents a journey;" "he who dreams he has lost a tooth shall lose a friend;" "he that dreams that a rib is taken out of his side shall ere long see the death of his wife;" to dream of swimming and wading in the water is good, so that the head be kept above water. A good share of the omens depend upon contrasts and not upon resemblances: "to be married denotes some of your kinsfolks are dead;" "to dream of death denotes happiness and long life;" and so on. Others of these dream-books analogies depend rather upon verbal resemblance and still others involve resemblances too subtle and peculiar to be readily explained. There is perhaps nothing more underlying the dictum that " dreaming about Quakers means that you will meet a friend soon," than the fact that the Quakers are a "Society of Friends;" a little more elaborate punning underlies the prediction that "to dream of a dairy showeth the dreamer to be of a milksop nature," and finally what a curious mixture of perverted analogy is reflected in the notion that to dream of "a zebra indicates a checkered life." Perhaps the next edition of the dream book will be more accurate and make it a striped existence.

The great parts that names and numbers play in superstitions of all kinds is so familiar that a few instances will be sufficient. It is well to bear in mind that these number and name predictions, in the course of their venerable and eventful lives, have been systematized and the gaps in the system supplied by arbitrary associations. Thus the modern fortune-telling books have an omen for each one of a pack of cards, or a set of dominoes, in which we find among what seems little more than an arbitrary assignment of the ordinary events of life, good and bad, pleasant and unpleasant, important and trivial, among the several cards or dominoes, here and there some underlying basis of analogy; hearts relate to love affairs, diamonds to wealth, kings and queens play important roles, the jack is about as often a lover as a knave, threes and sevens have special significance and double throws in dominoes es-

pecially the two sixes, as being unusual, have important consequences. So in folk-lore so many things are done just three times, or thrice three, or seven. The seventh child of a seventh child has special powers as we all know. The twelfth hour, that divides night from day is a momentous instant, as is also the cock's crow. "Against a warty eruption the leeches advised the patient to take seven wafers and write on each wafer, Maximianus, Malchus, Johannes, Martinianus, Dionysius, Constantinus, Serafion; then a charm was to be sung to the man and a maiden was afterwards to hang it about his neck." (Black.) In a similar strain the dream book informs us that if a number of young women not less than three nor more than seven assemble on a certain day and if as the hour strikes eleven they each take a sprig of myrtle and throw it, together with nine hairs from the head upon a live coal, and if they go to bed at exactly twelve they will dream of their future husbands as a reward of their pains and their mathematical accuracy. Not a few of number and name ceremonials are invested with their power by religious associations; the ill-luck of thirteen and Friday is commonly regarded as due to this source. In the northern English countries witches are said to dislike the bracken fern, because it bears on its roots the initial C (indicating Christ) which may be seen on cutting the root horizontally. (Dyer) The clover on account of its trefoil form, suggesting trinity is likewise good against witches. (Dyer.) A like explanation seems applicable to the efficacy of the cross and the cross-roads both of which enter in a variety of ways into folk-lore beliefs and customs. While numbers and names thus seldom form the whole basis of analogy by which the belief becomes plausible, they very frequently enter to emphasize and give point to other practices. The argument involved is extremely simple; it is nothing more than because two phenomena have in common the association with the same number therefore they will be connected in further respects. This slender line of connection forms the thread whereon are strung momentous omens, powerful recipes, dire predictions, and wise precautions against imaginary dangers, endless in number and variety.

The logic by which the treatments current in folk medicine acquire their efficacy is passing strange; at first acquaintance with this wonderland we are apt to imagine ourselves in some weird topsy-turvydom where everything uncanny and incongruous is greedily collected and the most bizarre and trivial doings become

endowed with marvellous efficacy. Upon closer acquaintance we discover some little order in the medley and, in spite of much that remains arbitrary and capricious, can trace the analogies according to which the various treatments are composed and the potions concocted. The common connection of toads with warts both as giving and curing them, is due to nothing more than the warty appearance of the toad's skin: similarly in Gloucestershire against earache a snail is pricked and the froth that exudes dropped into the patient's ear (Black), and this by reason of the many snail-like passages in the ear. Fevers being connected with heat and blood and both these closely associated with red, red things become efficacious in diseases characterized by fever. That this should be especially in vogue against scarlet fever is no more than natural, and it is related that when the son of Edward II was sick of the small-pox the physician directed that the bed-furniture should be red. (Black.) Other forms of such associations will be met with in the discussion of the doctrines of signatures and sympathy.

Folk-medicine forms a particularly apt field for the application of the two general forms of analogy indicated as prevalent among savages: analogies by contrast and the assignment of unusual effects to uncommon causes. If something is done with the right hand, doing with the left reverses the action; one set of directions apply to men and contrary ones to women; saying a thing backwards is particularly efficacious and so on. The prescription against hiccough that you should "cross the front of the left shoe with the forefinger of the right hand while you repeat the Lord's prayer backwards" (Black) may serve as the type of the one form of analogy, while for the other we may take Shakespeare's witches with their

> Round about the cauldron go;
> In the poison'd entrails throw.
> Toad, that under coldest stone,
> Days and nights has thirty-one
> Swelter'd venom sleeping got,
> Boil thou first i' the charmed pot!
> Fillet of a fenny snake,
> In the cauldron boil and bake;
> Eye of newt and toe of frog,
> Wool of bat and tongue of dog,
> Adder's fork and blind-worm's sting,
> Lizard's leg and owlet's wing,
> For a charm of powerful trouble,

Like a hell-broth boil and bubble.
Scale of dragon, tooth of wolf,
Witches' mummy, maw and gulf,
Of the ravin'd salt-sea shark,
Root of hemlock digg'd i' the dark,
Liver of blaspheming Jew,
Gall of goat, and slips of yew
Silvered in the moon's eclipse,
Nose of Turk and Tartar's lips,
Finger of birth-strangled babe,
Ditch deliver'd by a drab,
Make the gruel thick and slab;
Add thereto a tiger's chaudron
For the ingredients of our cauldron.
Cool it with the baboon's blood
Then the charm is firm and good.

We may gain an introduction into the domain occupied by the doctrine of sympathy through the best known survivor of that somewhat notorious doctrine, the common advice, "to take a hair of the dog that bit you." The origin of this takes us back to the medical system of sympathies that has appeared in various phases and at various times. We find Paracelsus a believer in it in the form of a "weapon salve" which is to be applied to the weapon that caused the wound and thereby heal the wound; weapon and wound having once been related as cause and effect, this is supposed to ensure further connection.

The system found wide circulation through the efforts of Sir Kenelm Digby. While Sir Kenelm's practices involved bad observation and ignorance of medicine, what gave the method its plausibility and induced the faulty observation was an underlying belief in the argument by analogy. His treatment may be gathered from a story he tells of a Mr. Howell whose hand was cut in an attempt to stop a duel between friends. Sir Kenelm arrives on the scene and asks for anything that had the blood upon it; he is given the garter wherewith the hand was first bound; this he places in a basin of water when suddenly Mr. Howell, who is unaware of what is going on, experiences a cooling effect and a relief from pain. When the garter is placed before a great fire, Mr. Howell experiences an intense burning in the wound, and so on. Still another form of this idea appears in the "sympathetic alphabet" in which two friends each cuts out a piece of his skin and has it transferred to the other; on this grafted skin an alphabet is tattooed

and when a letter is pricked on the skin of the one friend the other feels the pain at the corresponding point and thus intercourse is established. A still more curious form of the doctrine appears in an out-of-the-way pamphlet that lies before me as I write; its title (a German translation from the French) is, "The Thought-Telegraph: or the instantaneous communication of thought at any distance, even from one end of the world to the other by means of a portable machine. The most wonderful invention of our age." The true basis of the method we are told depends upon a "sympathetic-galvano, magnetic, mineral, animal, adamitic fluid;" the practice depends upon the alleged discovery of a species of snails placed in a sympathetic relation, so that ever after their movements are in harmony; accordingly each operator takes one of the snails and places it upon the alphabet chart; the snail crawls over the chart resting upon certain letters and the other snail however far removed will do just the same and thus the thought telegraph be established. Like Charles the Second's famous fish that would not add to the weight of a dish of water in which it was placed it lacks nothing but truth to be a great invention. Similar practices are still current: in the Netherlands the knife that cut one is rubbed with fat in the belief that as the fat dries the wound will heal. The relation may become more arbitrary as when to cure ague as many notches are cut in a stick as there have been fits and as the stick dries the ague is to disappear,—a form of reasoning readily duplicated among savages. Ruptured children are passed through a split tree and thus a sympathy is produced between child and tree, so that as the tree heals the child will be cured. A like sympathy is supposed to exist between celestial objects and human events; this is particularly applied to the moon, the moon's growth and wane indicating the fortunate times for growth and decay of earthly things. One must sow grain, cut the hair and perform sundry other operations with the increase of the moon to ensure increase of growth. The tides are similarly significant as the ever-pathetic Barkis "going out with the tide" sufficiently illustrates.

The doctrine of signatures seems founded upon the belief that no object or event is without profound significance for man's welfare; and the key to this significance is given in a hidden resemblance actual or ideal. The uses of things are suggested by their appearance. The Euphrasia or eyebright is useful in case of sore eyes on account of the bright eye-like spot in its corolla; special virtues are ascribed to the ginseng on account of the resemblance

of its roots to a human shape. The granulated roots of the white meadow saxifrage were regarded as efficacious against calculous complaints. The Solomon's seal is so called on account of the marks in the cross section of its roots and is used to seal wounds. Water soldier on account of its sword-shaped leaves was regarded as useful for gunshot wounds. The red rose suggests its use in blood diseases; and yellow flowers were used in liver complaints. The walnut was clearly defined for use in mental diseases, for its shape was that of the head, the outer green covering being the pericranium, the hard shell the skull, and the kernel the brain. Old ladies' thistle is for stitches in the side, nettle tea for nettle rash, hearts' ease for heart troubles. Plants whose parts resembled teeth were prescribed for tooth-ache, quaking grass against shakes, and so on. (Dyer.) The resemblances here involved are obvious enough; they are just such as underlie popular names of plants and the metaphorical use of terms. They form another illustration of how metaphor and analogy overlap.

By far the most systematic of all the doctrines founded upon analogy is astrology together with the various forms of alchemy and magic with which it is historically connected. Although this body of thought engaged the energies of many able and famous scholars it is difficult for us to see in it anything more than a system of resemblances and coincidences, elaborate and complex indeed, but requiring little more than a vivid imagination and a somewhat keen sense for far-fetched analogies. "This investigation," says the astrologer in Rydberg's "Magic of the Middle Ages," relies on the resemblances of things, for this similarity is derived from a correspondence and causality is interwoven with correspondence. Thus, for instance, we judge from the resemblance between the splendor of gold and that of the sun, that gold has its celestial correspondence in that luminary and sustains to it a causal relation. Another example: the two horned beetle bears a causal relation to the moon, which at its increase and wane is also two-horned; and if there were any doubt of this intimate relation between them it must vanish when we learn that the beetle hides its eggs in the earth for the space of twenty-eight days, or just so long a time as is required for the moon to pass through the zodiac, but digs them up again on the twenty-ninth when the moon is in conjunction with the sun. (Agrippa De Occulta Philosophiæ, I: 24.)

It will readily be seen how limitless are the results obtainable on such a system. Each planet becomes connected with a certain part

of the body and an argument such as the following becomes possible: "Since Capricornus which presided over the knees in the house of Saturn and all crawling animals are connected with the planet, the fat of snakes is an effective remedy against gout in the knees, especially on Saturday, the day of Saturn." (Rydberg.) Tables of correspondences were freely devised showing the representatives of the sun, moon, and five planets among the elements, the microcosm, animals, plants, metals and stones. Thus Mars was represented in these spheres respectively, by fire, acid juices, beasts of prey, burning, poisonous and stinging plants, iron or sulphuric metals, diamond, jasper, amethyst, and magnet, the vein of analogy lying in the fierce character of the god, whose name the planet bears. This idea of correspondence dominates the queer collection of odds and ends by which the old time astrologer worked his charms. "Here," for instance, he would say, "is a plate of lead on which is engraved the symbol of a planet; and beside it a leaden flask containing gall. If I now take a piece of fine onyx marked with the same planet symbol and this dried cypress branch, and add to them the skin of a snake, and the feather of an owl, you will need but to look into one of the tables given you to find that I have only collected various things in the elementary world which bear a relation of mutual activity to Saturn, and if rightly combined can attract both the powers of that planet and of the angels with which it is connected." (Rydberg.) Mr. Tylor thus ably characterizes the analogies on which this system is built and the uses to which it is put. "But most of his pseudo-science seems to rest on even weaker and more arbitrary analogies, not of things but of names. Names of stars and constellations, of signs denoting regions of the sky and periods of days and years no matter how arbitrarily given are materials which the astrologer can work upon and bring into ideal connection with mundane events. That astronomers should have divided the sun's course into imaginary signs of the zodiac, was enough to originate astrological rules, that these celestial signs have an actual effect on real earthly rams, bulls, crabs, lions, virgins. A child born under the sign of the lion will be courageous, but one under the crab will not go forward in life; one born under the waterman will be drowned and so forth . . . . Again, simply because astronomers chose to distribute among the planets the names of certain deities, the planets thereby acquired the characters of their divine namesakes. Thus it was that the planet Venus, became connected with love, Mars with war, Jupiter (whose ♃ altered in shape

still heads our physicians' prescriptions) with power and joviality. The various positions of the heavenly bodies at one's birth interpreted by such wild analogies, readily yield material for the prediction of future careers, vague enough to defy close denial and bold enough to claim readily foreseeable consequences as striking verification. Astrology perhaps represents the climax of the argument by analogy fully systematized and calling into play many of the resources of modern culture. What is so clearly represented in astrology appears to a less extent in other pseudo-scientific systems. We find it flourishing in palmistry and phrenology. We find other aspects of it in theosophy and mind cure. It captivates minds that are strong as well as those that are weak, and emphasizes the pricelessness of our scientific inheritance and the necessity of guarding it by the cultivation of sound logical habits of thought.

It only remains for me to call attention to certain general anthropological and developmental truths upon which the illustrations we have been considering have a bearing. We have seen what a widely extended genus the analogical argument compasses; and yet if we were to include under this head certain closely allied and yet readily distinguishable forms of thought it would be much wider still. I refer particularly to the use of metaphor and symbolism which like the children's make-believe with their dolls or fairies is none the less on the boundary line between the real and the fictitious. Myth equally readily passes from the unconscious to the conscious stage and much of what is plausible interpreted as an argument by analogy seems equally well a conscious symbolism and myth. That savages at least in all but the lower stages appreciate the use of myth is beyond all doubt. The primitive ceremonials are full of symbolisms involving the same mental habit, as does also their explanation of nature's changes. This mythological instinct, Mr. Tylor well says, "belongs to that great doctrine of analogy from which we have gained so much of our apprehension of the world around us. Distrusted as it now is by severer science for its misleading results, analogy is to us still a chief means of discovery and illustration, while in earlier grades of education its influence was all but paramount. Analogies which are but fancies to us were to men of past ages reality. They could see the flame licking its yet undevoured prey with tongues of fire, or the serpent gliding along the sword from hilt to point; they could see a live creature gnawing within their bodies in the pangs of hunger; they

heard the voices of the hill-dwarfs answering in the echo, and the chariot of the Heaven-god rattling in thunder over the solid firmament. Men to whom these were living thoughts had no need of the schoolmaster and his rules of composition, his injunctions to use metaphor cautiously and to take care to make all similes consistent."

The principle that what was once the serious occupation of men becomes in more advanced stages of culture the play of children, or is reduced from seriousness to mere amusement, finds illustrations in the mental as in the material world. The drum, once the serious, terrifying instrument of the savage warrior, and the rattle, once the powerful emblem of the medicine man, have become the common toys of children. The bow and arrow are used for skill and sport only. In a similar way the formidable and trusted argument by analogy finds its proper field in riddles and puns. When we put the question "Why is this object like the other?" we understand that some out-of-the-way and accidental resemblance is asked for, some not very close analogy, that provokes amusement but not belief; in many cases the resemblance is in the name only and degenerates into a pun. In such exercises of fancy we are employing the same faculties that our ancestors used in arriving at the customs and beliefs that we have been considering. The laws governing the progress of industrial arts, of mechanical inventions and social institutions seem thus to find equally ready application to the evolution of habits and customs in the mental world.

There is a further very suggestive generalization connecting three important lines of mental evolution: the evolution of the primitive man into the man of civilization; the evolution of the child into the adult, and the reverse of these processes in the decay or retrogression of faculties in disease or aberrant forms of mentality. The parallelism between the evolution of the individual and that of the race, has been carried out with great suggestiveness through many of the typical characteristics of the savage and of the child; the order of unfoldment of the several faculties and their mutual independence have been shown to be closely similar in the two cases. The dominant emotional traits of the savage, his impulsiveness and instability of character, his æsthetic tastes, these and others have been proven related to similar appearances in children, and in almost all the directions in which the principles of evolution would lead us to respect the parallelism to obtain, it has been possible to collect at least sporadic illustrations of its occurrence. It is in-

teresting to find in what would appear to be a somewhat out-of-the-way type of mental habit so striking an illustration of the same developmental law. We find to a limited extent at least, similar thought habits in savage and child; and still more strikingly do we find them in comparing primitive arguments by analogy with those reversions to outgrown conditions, those survivals in culture, that may not inaptly be regarded as diseased. The same law according to which the comparative anatomist explains the form and meaning of parts by reference to their embryological condition, as well as to the idiosyncrasies of disease, enables the psychologist to connect the traits of savages with those that survive from a culture which they are of to one which they are in. A simple reference to the illustrations already cited will suffice to show the extent of the parallelism; hardly a form of modern superstition, hardly a custom sanctioned by the unwritten tradition of the people, but what can be closely duplicated among the customs and beliefs of the untutored savage.

And, finally, throughout this chapter in the history of evolution, we obtain suggestive glimpses of the workings of a great progressive law. We are led to appreciate the means by which error is converted into truth, the slow and painful steps by which the logic of science is unfolded and mastered. When Lord Chesterfield relates that the people expected a fatal issue of the King's illness, because the oldest lion in the tower, of about the same age as the King, had just died, he cannot help commenting upon the wildness and caprice of the human mind, but Mr. Tylor more judiciously adds "indeed the thought was neither wild nor capricious, it was simply such an argument by analogy as the educated world has at length painfully learned to be worthless,but which it is not too much to declare would to this day carry considerable weight to the minds of four-fifths of the human race." We see that while progress has been made, there is no less need for continued effort. The logic of science has not yet gained the wide application it is destined to gain and is worthy of occupying; the remains of effete and misleading forms of thought still exist for mischief in our midst. But in the light of the teachings of anthropological psychology these phenomena appear in their true guise, testifying at once to the inherent progress in spite of reversions, and to the underlying unity of movement and design by which these phenomena acquire their deeper and more human interest.

PAPERS READ.

RELICS OF ANCIENT MEXICAN CIVILIZATION. By ZELIA NUTTALL, Assistant in Mexican Archæology, Peabody Museum, Cambridge, Mass.

[ABSTRACT.]

CONSIDERING how few relics of Ancient Mexican civilization have been spared to us, it is with particular pleasure that I now draw your attention to some valuable examples which came under my notice recently and seem to have been hitherto entirely overlooked.

The first and most important of these consists of an anonymous Hispano-Mexican MS., now preserved in the National Library at Florence, in Italy, and bearing the title of "The book of the life formerly led by the Indians, the superstitions they had and the evil rites they practised." It comprises one hundred and forty-four pages, eighty-six of which are covered with unusually fine pictures by a native artist. The accompanying text is evidently the work of a Spanish monk, whose identity I hope to be able to establish eventually. His account is undoubtedly contemporaneous with the invaluable works of Fray Bernardino de Sahagun, Fray Diego Duran, and Fray Motilinia and forms no unworthy companion to them. Indeed the manuscript contains so much that is new and valuable that I lost no time in applying for permission to publish it in fac-simile and thus to place it within the reach of my fellow students of Ancient Mexican ethnology. The permission has been accorded me and I have proceeded with the exact reproduction of the colored designs of the text by means of photo- and chromo-lithography. The work has progressed most satisfactorily and I expect to be able to issue next year, the fac-simile of the MS. accompanied by my English translation of the Spanish text with a commentary.

An interesting feature of the MS. is the representation of forty-five various symbolical designs such as were painted on, or woven into, the blankets (mantas) used by the Mexicans in their religious dances. I have pleasure in submitting to the members of the A. A. A. S., at this meeting, two proof sheets of this quaint and unique pattern-book. Although not to be found in any other known MS., these representations correspond closely with the descriptions given by Sahagun in his chapter "on the *mantas* used by the chiefs in their dances" and it is a noteworthy fact that Sahagun describes exactly the same number of designs as those represented in this MS. of the National Library in Florence. The Spanish text accompanying the pictures is of great value. The illustrations by the

native artist are not less so and prove him to have been free from Spanish influence, for he adheres closely to the ancient conventional forms and outlines characteristic of Mexican pictography. The proof sheet of page 89, which I also submit for inspection, portrays the four chief Aztec gods with their attributes, represented in the usual conventional aboriginal method.

The next ancient Mexican relic I have the pleasure of introducing to your notice is the magnificent shield of feather work, decorated with gold which has been preserved, for centuries, at the castle of Ambras near Innsbruck in the Tyrol. This shield belonged to the nephew of Charles V, the Archduke Ferdinand of Tyrol, and is described in the inventory of his collection of armour made after his death in 1596. Those present who direct their view to the slightly restored representation, in natural size of this splendid shield will, I am sure, share my surprise that its existence has been hitherto overlooked. It is a fact that the Austrian scientist Ferdinand von Hochstetter, although he knew that a shield was described in the earliest inventory of the Ambras collection, stated in 1884, that it had disappeared "leaving no trace whatever." This error was evidently based on the circumstance that the bulk of the Archduke's collection of armor, including the much discussed ancient Mexican feather head-dress, was removed, in 1806, from the Castle of Ambras to Vienna. On finding this feather head-dress only in Vienna, Ferdinand von Hochstetter naturally concluded that it was the sole piece of ancient Mexican feather work remaining of those described in the oldest inventory. Meanwhile, however, the shield remained well cared for, duly catalogued but unnoticed at Castle Ambras and with it two other less important but interesting ancient Mexican relics. These are: a large fan such as was used by Aztec ambassadors as a symbol of office and a much damaged wooden shield which once had been covered with turquoise mosaic. I have been favored with permission to photograph and publish illustrations and descriptions of these specimens which will appear shortly in an essay "On Ancient Mexican shields," in the "International Archive of Ethnography," published at Leyden, Holland.

Meanwhile the following short description will explain my illustration. The Ambras shield is in a truly remarkable state of preservation. It is made of light strips of cane stalks held together by closely interwoven threads of Maguey (Agave) fibre. This foundation is stretched on a flat wooden hoop and is covered with native paper on which the feather mosaic work is fastened. The rose-red background and the fringe around the shield are formed of highly prized feathers from the Tlauhquechol or roseate spoon bill, the use of which was confined to chieftains of highest rank. I found traces of the former existence of a beautiful fringe of quetzal tail feathers hanging from the lower part of the shield. A large bold representation of a monster, the fabled Ahuitzotl? a kind of amphibious animal is executed in light blue and dark purple feathers. The conventional pictograph of water in front of the monster is also formed of light blue feathers.

All outlines of these representations are covered with skilfully applied narrow bands of raised gold-leaf. The claws of the monster, its eye and fangs, etc., are also formed of burnished gold-leaf firmly held in place by some strongly adhesive substance which has almost entirely withstood the ravages of time.

THE NEZ PERCE COUNTRY. By ALICE C. FLETCHER, Assistant in Ethnology, Peabody Museum, Cambridge, Mass.

[ABSTRACT.]

THE paper is in explanation of a map of the Nez Perce country drawn by a native of the tribe, and showing the location of seventy-eight villages, and giving the Nez Perce names of mountains and streams. A summary of the divisions and groups of these villages is given and an outline of the tribal organization with a brief account of the ancient mode of living in the villages, and some deduction concerning the relation of the environment to the development of these people. A short biographical sketch of the Indian who made the map is also given and his photograph attached.

The legend accompanying the map gives the derivation of the village names and other information concerning them.

AN EXPERIMENT IN HUMAN STIRPICULTURE. By ANITA NEWCOMB MCGEE, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

IT is not generally known that a carefully planned and methodically conducted experiment in human stirpiculture, probably the most extensive and systematic of modern times and civilized people, was carried on during the years 1868 to 1879 in central New York. The originator of the experiment was a zealous but logical enthusiast, the late John Humphrey Noyes; the purpose was the promotion of sanctity; the place and the means were the Oneida Community. In early life, Noyes founded the peculiar sect called Perfectionists, which, in 1848, gathered disciples to the number of eighty-seven at Oneida. Here community of goods and also of persons was practised, a system of complex marriage in which the amative and propagative functions were separated having been established.

Until 1868 the birth rate in the community was carefully limited, but at this date financial success being assured and the members having increased to 250, the experiment in stirpiculture was begun. Its primary object was the increase of sanctity in succeeding generations in order that sin, disease and finally death might be abolished. Physique, intellect, hereditary qualities, mutual attraction, etc., were secondarily considered.

The first principle of this stirpiculture was continued in-and-in breeding, with judicious admixture of foreign blood from time to time. Its second principle was the careful selection of individuals. From 1869 to 1880, sixty children were born in pursuit of this plan. Of these, five died at birth, from unforeseen causes depending on the mothers, and one child was acknowledged a failure physically. Otherwise the experiment was progressing admirably, the children being given the best of care, when an unexpected result caused the failure of all Noyes' plans—the spirit of monogamy, ruthlessly kept in check before, became so strong in consequence of the mating of one-third of the community for stirpicultural purposes, that the complex marriage system was given up in 1879. The dissolution of the Oneida Community by mutual consent followed a year later. Noyes, foreseeing the end, had retired from Oneida. He died in 1886.

Of the stirpicultural children, only one has since died. The others, now aged eleven to twenty-two years, are on the whole somewhat above the outside average in physique and intellect. The blood of these children came largely from farmers and mechanics, with a strong infusion from the intellectual Noyes family. It is therefore noteworthy that of the oldest sixteen boys, ten are in business as clerks, foremen, etc.; one a musician of repute, two students of law and medicine respectively, two at college and only one following a manual occupation, *i. e.*, a mechanic. Of the oldest six girls, two are at college, and one a student of the kindergarten system.

But the main object of the experiment has not been attained. Only one of the children is a Perfectionist and he was born of an uncle and niece, both Noyeses. Of the rest, but few are regular church members. This experiment would therefore seem to show that while the race could doubtless be improved by more attention to stirpiculture, yet when directed to the perpetuation of a belief, success cannot confidently be expected.

[Printed in full in the American Anthropologist, Vol. IV, 1891, p. 319.]

THE PSYCHICAL STUDY OF CHILD LIFE. By LAURA OSBORNE TALBOTT, 927 P St., Washington, D. C.

[ABSTRACT.]

"O little feet! that such long years
Must wander on through hopes and fears,
Must ache and bleed beneath your load;
I, *nearer* to the wayside inn,
Where toil shall cease and rest begin,
Am *weary*, thinking of your road."

—*Longfellow.*

IN order to write the history of English literature, Taine tells us that he sought it in the psychology of the English people; likewise in writing the biography of a great man, the author seeks to find the psychical ten-

dencies of the child mind of his subject, so in studying all history of the past, we seek illumination upon those points which lay bare the complex processes of the human soul. May we not in studying the development of the soul's growth seek its psychology?

Historical methods have been revolutionized during the last century. May not educational systems be improved by more attention to psychological principles.

Great has been the amount of labor and of time expended upon both historical researches and upon the study of life of every kind upon the earth, but *exceptional* have been the students of child life.

The thought that "the child of to-day is to become the man of to-morrow" suggests a great responsibility resting upon the present generation. Are we to allow this monster of our present civilization to succeed itself in the twentieth century, or are we to seek to purify the springs of life from which it issues? Of all the educational questions engaging public notice at the present time there is none that gives enough attention to the development of the individual at a sufficiently early period of child life, nor are there any that adopt a thorough philosophical method towards detecting the peculiarities of the individual. The first five years are the most important period of a child's life; during this formative period it gains acquired perceptions most rapidly, its inherited tendencies become fixed, and at that time, the *creative* power of the mind is most easily aroused.

What a rich field for study is the soul's growth of the young child. No one need to look for a more interesting field of study than this affords to every reflective mind. Who is equal to it? Who can look upon a young child without intense interest, wondering meanwhile whether the energy hidden in that young brain will develop into a Wilkes Booth or a Lincoln, a Guiteau or a Garfield. With what care should its growth be watched and tended. Certainly with as much care as is generally given by many persons to a tree or a brute beast.

Our old friends Comenius, Pestalozzi and Froebel have made us forever debtors for their philanthropic efforts to lift humanity from the Slough of Despond; but even greater insight into the depths of the human mind is needed than that which has been bestowed upon us by their noble labors.

A surgeon being once asked the way to cure a felon on the finger, replied, "Cut it to the bone." So in educational training the deeper insight that is obtained into the psychical condition of the being, the better foundation there will be to build upon.

There are undeveloped depths of power in the human mind, which have never been sounded, a *terra incognita*, even to trained psychologists, but the demands of the times must soon compel a more general study and more enlightened treatment of the subject.

Never was there a time in the history of civilization, so marked as a transition period, as that of the nineteenth century. But with the increase of facilities for rapid transit, and telegraphic communication and other means of development, there seems to be no abatement of such evils as

the troubles between labor and capital, the questions of divorce, suicide, insanity and crimes of all kinds.

It would seem as if the engine of civilization was in the charge of a drunken or stupid engineer, and the faster the speed, the more danger of destruction. The demand of the age is for more creative brain power or for an intellectual force that may be able to harmonize the discordant elements of civilization.

According to Herbert Spencer and John Fiske, "The process in which life essentially consists is the continuous maintenance of an equilibrium between the organism and its environment. Life, also including intelligence as the highest known manifestation of life, is the continuous establishment of relations within the organism, in correspondence with relations existing or arising in the environment."

It is evident that this lack of equipoise or correspondence between the outer and inner life of the individual causes many failures in life, and it should be the duty of the psychical expert to assist in the harmonious development of the individual.

No matter how much veneering may be done by our educational methods, the defects are sure to become apparent sooner or later, breaking out like a sore, either in a case of embezzlement, divorce, insanity or crime of some kind.

All questions arising from the mixed condition of our present civilization, must eventually revert to the final question. How can we best develop all the higher energies of the individual, and how can we best destroy its evil tendencies?

Wordsworth tells us "Heaven lies about us in our infancy." This is but half a truth for children inherit qualities which are as likely to render them demons as angels.

More and more, our educators are coming to realize the necessity for giving greater study to the psychical development of child life.

One of the most important points made by Froebel was the danger arising from an overdue development of self-consciousness.

For ages the human race has been the prey of every kind of crime. Nations have risen to eminence and power. Governments have sunk into degradation and into insignificance; the same fate is before us unless we give to each child its *inalienable* right to develop its whole nature to the highest plane possible.

What an uplifting to all civilization would take place in another generation even, if we could have kindergartens attached to our public schools. Although many wise persons are elevating their own families, no general movement has taken place to uplift the masses by this method. If it were only from a selfish motive, would it not be wise to attempt this, for the ancients teach us that one member cannot suffer without injury to the whole body.

Senator and Mrs. Stanford enjoy telling the incidents in their son's education which first roused his dormant faculties and interested them in the establishment of kindergartens.

Vain attempts have been made for several years, by the citizens of Washington, to have kindergartens connected with the public schools. Congress turns a deaf ear to such appeals, but still goes on appropriating large sums of money for erection of stone or bronze memorials, but not one cent to eradicate the microbes of evil from the minds of our children. Would it not be well to give more money for the education of the youth who are to be the future preservers of our liberties.

Is it not a relic of antiquity to worship our ancestors? Is it not time to break our shell, look to the future of our children and in Tennyson's words, "Rise from our dead selves to higher things?"

RELATION OF A LOVELAND, OHIO, IMPLEMENT-BEARING TERRACE TO THE MORAINES OF THE ICE SHEET. By FRANK LEVERETT, U. S. Geological Survey, Madison, Wis.

[ABSTRACT.]

THE studies now in progress under the direction of Pres. T. C. Chamberlin are of a sufficiently detailed character to bring out the several episodes or sub-epochs of the great ice-age in their proper succession and in a rough way to indicate time intervals. When this line of investigation is extended over the whole of the glaciated district the results give promise of valuable aid to the anthropologist in determining the relative ages of such glacial formations as may contain the works of primitive man. Already some results of value are obtained as appears below.

Loveland, Ohio, is situated in the Little Miami valley some twenty-five miles north of the glacial boundary and consequently lies within the drift-covered area. The terrace from which Dr. Charles L. Metz obtained implements connects near King's Mills (some ten miles north of Loveland) with a moraine of the last glacial epoch in such a manner as to show clearly that it is of the same age as the moraine, there being a gradation and blending of the terrace and moraine at point of connection, as is common with moraine-headed terraces. The moraine occupies the slopes and bottom of Turtle creek (a tributary of the Little Miami entering that stream near King's Mills) down to the level of the implement-bearing terrace as well as the uplands on either side which stand 150 feet or more above the terrace. This fact is of much significance since it shows this moraine to be of later date than the erosion which produced Turtle creek valley. From a study of several streams in that vicinity it appears that the amount of erosion accomplished since the time when the ice occupied this moraine is much less than that accomplished between the first great invasion of the ice sheet and the later advance which produced this moraine. The implement bearing terrace therefore dates from the maximum advance of a late invasion of the ice-sheet which occurred near the close of the ice age. There was, however, a series of at least a dozen moraines formed by the ice sheet subsequently to the moraine under discussion, as

it halted in its final retreat to the north, consequently there is ample room for implement-bearing terraces of date relatively much more recent than that of the Loveland terraces and yet of glacial age.

THE CUSTOMS OF KAVA DRINKING AS PRACTISED BY THE PAPUANS AND POLYNESIANS. By WALTER HOUGH, U. S. National Museum, Washington, D. C.

[ABSTRACT.]

DESCRIBING the plant, chemical composition of the root and preparation of a narcotic beverage therefrom. The ceremonies connected with the drinking of kava preparation, serving and the effects of the drug are described. A comparison with other beverages prepared by chewing is made. The origin and propagation of the customs are discussed. After remarks upon narcotics and stimulants, the paper closes with notices of the use of fermented drinks among rude tribes.

[To be printed in full in Annual Report of National Museum.]

SIOUAN ONOMATOPES, INTERJECTIONS AND PHONETIC TYPES. By REV. J. OWEN DORSEY, Takoma Park P. O., D. C.

[ABSTRACT.]

THIS paper treats mainly of the onomatopes or sound-roots, the interjections, and phonetic types of the Dhegiha, a language spoken by the Omaha and Ponka tribes of the Siouan or Dakotan linguistic family.

The writer has collated, as far as possible, the Dhegiha examples given in this paper with their equivalents in seven other Siouan languages; but wherever the language to which an example belongs is not named, the root or word in question is in the Dhegiha. While many roots now denote the effects of certain acts, it is very probable that some of them originally referred to the sounds made in producing those effects. An English writer in the last century collected a number of examples in his own language, to show that a certain collocation of consonants at the beginning of a word generally designates the class of ideas intended to be conveyed by it.

Thus, *st*, idea of *rest, stability*, as in stand, stay, stop, stick, still, etc. (but also idea of *motion*, as shown in the words given in Tooke's Diversions of Purley); *sl*, idea of *sliding*, etc., as in slip, slime, etc. Compare words in *gl:* glide, glance, etc. The writer gives examples of phonetic types which he has discovered in the Dhegiha, Kwapa, Kansa, Osage, Tciwere, Winnebago, Dakota, and Hidatsa languages. The paper was illustrated by charts.

[To be printed in full by Bureau of Ethnology.]

OUTLINES OF ZUNI CREATION AND MIGRATION MYTHS CONSIDERED IN THEIR RELATION TO THE KA-KA AND OTHER DRAMAS OR SO-CALLED DANCES. By FRANK HAMILTON CUSHING, Albion, Orleans County, New York.

[ABSTRACT.]

(1) ESSENTIALLY dramatic and religio-sociologic character of primitive dances.

(2) Relation of such dances in Zuñi, to the clusters or septs of gentes or kinties.

(3) The paraphernalia, costumings, action, songs, and rituals of them, to myths of creation, etc.

(4) Character of primitive drama or dramaturgy as contrasted with civilized drama.

(5) The civilized drama, spectacular and dramatic. Primitive drama reproductive and dramaturgic. Instance: The supposed necessity of dramatic fidelity in unseen preparations for, no less than in public enactment of, dramas. Example: Repetition in pantomime or otherwise of all portions of creation myth up to the beginning of specially dramatized legend.

Illustration of the foregoing by readings from outline myths of creation and migration, and oral comments on relations of these to ceremonials of the priesthood of the bow drama of the origin of corn, etc., with descriptions of latter.

[This paper will be printed as a Bulletin of the Bureau of Ethnology.]

ORIGIN OF THE NAME CHAUTAUQUA. By ALBERT S. GATSCHET, Bureau of Ethnology, Washington, D. C.

[ABSTRACT.]

THE name Chautauqua, so well-known through the educational institutes named after it, has been interpreted by "amateurs" in very different ways. The article states at length the linguistic reasons, why this name, which is worded in the Seneca-Iroquois language, still spoken in western New York, cannot signify anything else but: *one has taken out fish there.* It is pronounced by these Indians T'kä^{n}tchata'kwä^{n}, and the old English and French documents vary enormously in their mode of writing it. It is probable that fish were taken out by the Indians from Lake Chautauqua to stock the brooks and ponds of the vicinity. The author proposes to change the orthography of Chautauqua into the more scientific Chatakwa.

BURIAL CUSTOMS OF THE HURONS. By CHAS. A. HIRSCHFELDER, U. S. Vice Consul, Toronto, Canada.

[ABSTRACT.]

THE region to which I desire to carry my audience is one full of historic interest, made doubly so from the fact that Parkman has so frequently referred to this part of N orth America in his valuable writings, and also from the fact that the early Jesuits first commenced their missionary labors in this district. No matter how we may view or regard the work

which the Jesuits had undertaken in christianizing the Indians, we can but admire their great zeal, endurance and indomitable courage, and students in quest of knowledge concerning the traits of the Indians are deeply indebted to these missionaries for their keen observations and copious notes which give us such an insight into the aboriginal manners and customs. The Huron Indians inhabited what is now known as the County of Simcoe, in the Province of Ontario, Canada, situated between two large bodies of water—on the north lies the Georgian Bay, with its 30,000 islands, and on the south the clear crystal waters of Lake Simcoe. The locality was in every way an ideal one for an aboriginal site. The country was well wooded, game was plentiful, large and small lakes abounded, which not only gave a plentiful supply of pure water but were also full of fish, while small streams flowed in various directions. With such favorable surroundings it is not surprising that the Hurons had remained in the same locality for centuries, and had it not been for their implacable foes, the Iroquois, they might possibly be there yet. But in 1649 their dreaded enemy descended upon them and slaughtered Indian and Jesuit alike, and the few who escaped sought refuge in the islands of Georgian Bay, whence shortly afterwards they removed to Lorette, near Quebec, where the remnants of that once great tribe can now be found and are known by the name of Wyandotts. The County of Simcoe has proved a most prolific field for the archæologist, and for fifteen years I have devoted much time to the examination of earthworks and to the collecting of relics. I have secured some four thousand objects in stone, shell, bone, pottery and copper. Many of the specimens deserve to be ranked among the finest of the so-called Neolithic period. As reports of the various forts and earthworks, which I have surveyed, have appeared frequently in public print, I shall not now refer to them. I desire simply to make a few remarks on the burial customs of the Hurons.

Their places of sepulture are of three kinds:—the ossuaries (or depositories of human bones), single graves, and mounds. The ossuaries contain the remains of from a few to several thousand bodies, and it is principally in these that specimens are found. I opened one of these large pits in South Orillia township and dug through human bones nearly ten feet deep. In order to account for the interment in such large numbers in one spot, it is necessary to explain the custom which resulted in burial of bones. The "Feast of the dead" was one of the Indians' most solemn and religious rites; when an Indian died, it was the custom to erect a rough stage, upon which the body was placed. Every eight or ten years the bones, were collected (those of the recent dead being cleaned of flesh) and all were buried in one large hole. The functionaries on whom the duty of scraping the flesh from the bones devolved were denominated "bone pickers." As the skeletons were cast in promiscuously, it is very difficult to find perfect crania among the bones. From thirty of these ossuaries I have only succeeded in securing about forty perfect crania. One skull was particularly interesting from the fact that it had been broken through in three separate places, and yet the Indian had lived for years afterward apparently as the wounds were completely healed. When one has seen an

ossuary it is easy to recognize them, owing to the circular depression of the surface, which is traceable to the settling of the earth thrown over the bones. One singular circumstance in connection with these ossuaries is worthy of mention, and it is that they either contain many relics or are entirely devoid of them.

With regard to the single graves, of which I have opened some 350, not over fifty contained anything but human bones. In certain cases the bodies were in a sitting posture, but no rule was followed. The sepulchral mounds are from three to four feet high and about sixty feet in circumference, and of no regular shape. These contain from six to twelve bodies, placed about two feet apart. Differences in the shape of the crania are observable in many of these sepulchral places. This may be accounted for by the practice of attaching prisoners of war to the tribe and also by that of occasionally uniting the remains of a shattered tribe with a tribe that had conquered. Besides intermarriage among members of the same clan was forbidden by some tribes, so that if a member of the Turtle Clan aspired to the paternity of a Romulus or Remus, it behooved him to seek the affections of a lady from some other clan than his own. While, as already stated, I have observed a considerable diversity in the crania of the ossuaries, mounds and single graves, the dolichocephalic type is most prevalent. It is by many believed that the burial of articles with the dead was a religious act, but my own observations do not lead me to think that it was necessarily so. We know that the Indians lived strictly up to their belief and if it had been an act of religion to thus bury articles I maintain that in each and every grave some articles would be found. But, as I have pointed out, the single graves do not, in many cases, contain anything, and where the large ossuaries have been carefully examined some of them have not contained a pipe or bead, while a single ossuary in close proximity might contain a thousand articles. Now my theory is this, if one of these "Feasts of the dead" should occur during a propitious season many articles could be spared, but if a famine stared the Indian in the face, which frequently happened, they would be too poor to spare articles, and it appears to me that placing objects with the dead was not a religious act but a tribute of respect.

That the Indians traded over a vast extent of country is evidenced by the fact that we find southern shells, *Pyrula perversa* and other species, in the northern graves, while in the south copper implements are found which show by their laminated structure that they are of aboriginal workmanship and the material is identified as coming from the Lake Superior deposits from the large amount of silver it contains.

THE MESSIAH RELIGION AND GHOST DANCE. By JAMES MOONEY, Bureau of Ethnology, Washington, D. C.

[ABSTRACT.]

THE Messiah religion and the ghost dance were discussed by the author, who spent last winter and spring with the wild tribes in the southwest,

investigating this subject under the auspices of the Smithsonian Institution. The idea of a redeemer has been common to many subject peoples in all ages, and the present Messiah craze is by no means the first which has appeared among the Indians, although perhaps the most widespread in extent. It originated among the Piutes about twenty years ago, but attracted no great attention until about two years ago, when the prairie tribes sent a large delegation to the Piute prophet to learn the doctrine and the ceremonial songs. After crossing the mountains the new religion spread rapidly among nearly all the tribes from the British border to New Mexico. In its leading idea it is an adoption of the white man's doctrine of a Redeemer, for the confounding of the white man himself. Civilization and the stranger will be swept away and the old Indian life will be restored. The movement is not warlike in any sense. The frontier ghost dance under the moonlight, with all the weird accompaniments, was described, together with the mesmeric performances, and the plaintive musical songs in which the Indians recall the old happy life that is gone from them.

[The full paper will be published by the Bureau of Ethnology.]

ON THE DISTRIBUTION OF STONE IMPLEMENTS IN THE TIDE WATER PROVINCE. By W. H. HOLMES, Bureau of Ethnology, Washington, D. C.

[ABSTRACT.]

THE tide water region of Maryland and Virginia furnishes only fragmental forms of rocks. These were brought down from the highland by the rivers and are consequently in the form of boulders, pebbles and sand; each river transported its own peculiar materials and distributed them in its own peculiar ways. It is observed that certain features of the stone implements of the region are local and that these features depend upon the character of the local material. Thus in the section where quartzite predominates, quartzite tools prevail; and, where quartz is most abundant, quartz tools prevail; also that where the boulders are large the tools found are large, and where they are small the tools are small. It is further seen that districts not supplied with raw material have imported tools varying in size, shape and material with the nature of the materials furnished by neighboring districts. In studying the art of a given district it is therefore necessary to consider carefully the nature of the available materials, their availability, texture, fracture and, if fragmental, their size and shape, before questions of race, culture and age are considered.

ABORIGINAL NOVACULITE QUARRIES IN ARKANSAS. By W. H. HOLMES, Bureau of Ethnology, Washington, D. C.

[ABSTRACT.]

RECENT examinations have shown that numerous ancient diggings located in the mountainous parts of Arkansas and believed formerly to be

Spanish mines, are quarries where the aborigines obtained novaculite for the manufacture of implements. These quarries are numerous and the pitting is on a grand scale. Fragments of the flinty rock have been broken off by hammers aided by fire and reduced on the spot to approximate form. Many stone flaking hammers are found, and the refuse of flaking forms high ridges around the margins of the pits.

STUDY OF A DWARF. By Dr. FRANK BAKER, Washington, D. C.

[ABSTRACT.]

ANTHROPOMETRIC and vital statistics with reference to an abnormally small human individual with some comparisons with other recorded cases.

THE LENGTH OF A GENERATION. By Prof. C. M. WOODWARD, Washington University, St. Louis, Mo.

[ABSTRACT.]

THERE are three periods connected with vital statistics liable to be confused:—

1. The average length of human life.
2. The average age of persons now living.
3. The average difference in age between father and son.

The last period constitutes the LENGTH OF A GENERATION, and has little to do with the length of life.

THE ESSENTIALS OF GOOD EDUCATION, WITH A NEW CLASSIFICATION OF KNOWLEDGE. By Prof. WM. H. SEAMAN, Washington, D. C.

A GOOD education may be defined as that education which most fully develops the normal mind in all directions, and gives the individual the largest capacity for effective action that his organization will permit.

Anything less than this is an imperfect education, either in amount or kind.

Most people in the United States are educated in the public schools, and these schools are usually controlled by a board of citizens, who represent public opinion in school matters. It is one of the legitimate functions of a scientific body like the American Association, to assist the formation of a correct public opinion on common school education, and one of the most important duties of school boards is the selection and arrangement of school studies.

The Bureau of Education recently published the results of a systematic

inquiry, which for the first time enabled a comparison to be made of the study schemes in actual use in a large number of our public schools. Very great diversity is shown to exist in these schemes in a way that renders it clear that no general principles for their construction are recognized. Before a study scheme for the masses can be arranged on a scientific plan, we must necessarily survey the whole of human knowledge, and determine the relations of each part to the other, and to the ordinary activities of human life.

A very slight examination of the study schemes in actual use in the public and other preparatory schools, and the colleges to which they lead, will show that these relations are neither determined nor in most cases considered, unless in a partial and unscientific manner. The public school systems of the United States have been mostly organized on the basis of methods which originated in, and were adopted by the New England states. These again were influenced by European university ideas as to the elements of a good education.

In the revival of learning at the close of the middle ages, a language for common use by all learned men was very desirable, and Latin, being adopted as such universal language, became the key to all learning. Among educated men it was not properly a dead language, it was a written and spoken tongue. In addition to Latin, mathematics, history and philosophy in the old or Aristotelian meaning formed the essentials of a good education, as then understood. Its character has been tersely summarized by president Dwight, in his article on "what a boy should know at eighteen;" in these words. "The classics and mathematics were held to be all that the schools should teach, or the boy should learn."

Just so far as this system rested on classical learning it was largely destitute of the fundamental ideas that dominate modern society. Christian ethics were not recognized in the classic ages as rules for the conduct of life in its ordinary channels ; even in the middle ages they were regarded as articles of faith, rather than rules of conduct.

Inductive reasoning was not considered an essential basis of truth, and most of the facts themselves were unknown on which the more important inductions of modern times rest. The idea of universal education itself was an innovation and an experiment.

The natural growth of our school systems has been mostly in the direction of its first impulses. The inherent conservatism of many teachers has prevented them from seeking to adapt education more perfectly to the wants of modern life. The ambition of all who passed beyond the primary school was directed to classical learning as the crowning result and ultimate test of a good education. In this manner the Latin language, originally the means to an end, became for most pupils the end itself.

Meantime a new and different body of knowledge has been assembled since the days of Linnæus, wholly distinct from classical learning in its subject matter and methods, that are so modern as not to be found in the categories of the ancients.

By a peculiar limitation of meaning not found in all our dictionaries, this kind of knowledge is called science, a term that should properly be held to cover all kinds of exact learning. It relates principally to two general subjects, chemistry and biology. This last term is as yet so little known, that in the inquiry by the Bureau of Education before referred to, it was then thought unwise to use it, because it was believed that many teachers were ignorant of its meaning.

This scientific knowledge has been chiefly accumulated by independent students who had an irresistible love for the investigation of nature by observation, and also by men who used it for some purpose, such as physicians or sportsmen. Up to recent times, these were men generally outside of the recognized higher institutions of learning, and received but little assistance from the prevailing systems of education.

So potent is the idea that a good education must have a basis of classical learning in the dead languages, that not one of the colleges for the higher education of women alone, admits students for a degree who have not laid a foundation for classical study by a preliminary knowledge of Latin, and many colleges for men are still in the same position. And further, it is a very few years since any of our colleges selected presidents from the ranks of chemists or biologists, president Eliot being we believe the first, and remaining for a long time an exception in this respect.

These statements are made only to call attention to some of the salient features of a struggle now some years in progress, between the teachers and advocates of science, and the classical school.

The first development of scientific education in this country was by special independent schools, and it is still largely taught in such schools. Its entrance into the older institutions of learning has been effected under the name of optional courses, which have been established by the managers of these institutions in response to a popular demand for scientific knowledge, rather than by any impulse in this direction from within the schools themselves. The large and increasing number of students, who elect scientific courses in our colleges, shows that in popular estimation, scientific is worth at least as much as classical training. This popular judgment is based on the belief that the new education is better adapted to the requirements of modern life than the old. It is undoubtedly correct, and the boards of control of our public schools should be guided by such judgment.

Our definition of a good education at the beginning of this article, demands in the arrangement of a study scheme, a survey of all knowledge, the relations of all parts to human life, the average mental condition of the pupils, and their possible development under the given conditions.

The last two conditions are variable for different localities, the first two will be substantially similar for all civilized communities.

Before the true relations of knowledge to human activity can be well understood, it must be classified, or systematically arranged. Many systems have been proposed by different writers from Aristotle to Herbert

Spencer, who says that no serial classification is possible. He admits however, that for education something of the kind is necessary, and after comparing the old systems, I venture to propose the arrangement in the following table as well adapted for our purposes.

Language covers all means by which ideas are conveyed from one mind to another. A tableau is as much a way of telling a story as a series of words, and a piece of sculpture is a frozen tableau.

For itself language has no value whatever, and every different language is a hindrance to the welfare of mankind by preventing the free interchange of thought. The prevalence of a universal language will be one of the advantages of the future. As a means of mental discipline, the study of language is worth no more than any other study. Any form of systematic mental activity is a mental discipline, and even if it were the study of checkers, it would undoubtedly fit the mind for sustained and regular effort, but no one for that reason would suggest the study of checkers as part of a school or college course.

Language has been praised as a mental discipline chiefly on account of the grammar; but experience has shown that the grammatical method is not the best method to acquire a useful knowledge of a language, hence unless it is maintained that grammar should be studied merely for mental discipline, it has no value at all. Considered merely as a means of mental discipline, no study has any right to particular regard, because all are substantially equal in this respect. The sole test of the importance of any study or branch of knowledge should be its adaptation to help the student to reason and to do, and not merely mental discipline, or literary culture.

Mathematics includes everything involving quantity. Pure mathematics relates to abstract numbers, and applied mathematics to concrete quantities. Mathematics enters into all learning as a condition of exact thought, but the higher mathematics have but little or no relation to the daily life of the average citizen.

Chemistry relates to the nature and constitution of matter in both its molecular and atomic condition, and a knowledge of its fundamental principles is absolutely essential to correct reasoning about any material things.

Biology relates to the structure and development of living beings, including the human race. Human history is simply the following or tracing out in two parallel lines, the successive phenomena of the biology of man, as exhibited in the development of his mental powers, and the machinery of his social organization. It bears to him as an animal, precisely the relations that the organization of a bee hive or an ant hill bears to the bees or ants.

The interdependence and mutual relations of different parts of learning become more pronounced as the subdivisions recede from the typical forms of the classes of knowledge. Thus the words of a language are one means of working out history, all of the fine arts are dependent on me-

LANGUAGE.	MATHEMATICS.		CHEMISTRY.		BIOLOGY.	
	PURE.	APPLIED.	MOLECULAR.	ATOMIC.	BOTANY.	ZOOLOGY.
Ancient.	Arithmetic,		Gravitation,		Including Anatomy and Physiology of plants and animals.	
Modern.	Algebra,	Surveying,	Heat,	Descriptive,		
Elocution,	Geometry,	Topography,	Light,	Theoretical,	Fungi,	Protozoa,
Grammar,	Trigonometry,		Electricity,		Algæ,	Metazoa,
Philology,	Calculus.	Astronomy,	Magnetism.		Lichens,	Insects,
Rhetoric,		Mechanics.		Mineralogy,	Mosses,	Fishes,
Logic,				Geology.	Ferns,	Reptiles,
Music,					Phenogams.	Birds,
Drawing,						Mammals,
Painting,						History,
Sculpture.						Psychology,
						Sociology.

chanics for their instruments. Astronomy invokes the aid of chemistry, and geology is very much indebted to biology for many of its fundamental data. Mechanics requires mathematics to determine forms of matter and quantities of force, and relies on chemistry for the liberation of energy, as in the steam engine, which is only a device for changing the molecular motion of heat into the mass action of the moving parts of the machine.

The four great classes of knowledge above specified are regarded as equal among themselves in importance. Hence no one can properly be called well educated, or possessed of a good education who is destitute of a knowledge of the fundamental principles of either of these classes.

Neither is any scheme of study complete as a full course, which does not include them all. Yet nothing is more common than to find the last two neglected, if not entirely ignored, especially in finishing schools for girls. The details of the classification are not essential to the strength of this argument: the breadth of meaning given to the term chemistry for example may not be generally acceptable, but no other term seemed so well adapted for the purpose. Again, the objection is often made to our present study schemes that too many things are taught.

It is doubtful to the writer if this objection is often properly made, but it would be very easy to teach too many branches, without at all teaching the fundamental principles of the four great divisions of knowledge as above stated. Neither does a little human physiology, nor a little study of phenogams constitute biology as it should be taught, because such instruction is too imperfect, and no general view of nature is obtained.

The child derives much benefit in school life from the enforced habit of order and punctuality, which are independent of the subjects taught, and are a feature of especial value in the public schools, where all pupils are equals before the law, and the influences which are potent to obtain personal favors in private schools are unknown. Such habits of systematic activity will be formed in any well ordered school, although too often attributed to classical study, the real advantages or benefits of which have usually been the knowledge of ancient history obtained from the classic authors, teaching the relations of human nature to government, etc.

But we live in a material world, and all the conditions of life necessary to a healthful development of our existence depend on our material environment. What we call the progress of civilization is a material progress, upon which even our ethical improvement hangs, as is fairly well established by the modern methods of missionary work. Notwithstanding this fact, the last two divisions of our quadrivium are neglected in nearly all our schemes of study, while the first two have a disproportionate share of attention. It is the last two which have the most intimate connection with our welfare, both as individuals and members of society. A merely literary knowledge of words and authors, or of abstract numbers is not so well adapted to enable us to live better and happier than heretofore, as a knowledge of ourselves as living beings, and of the constitution of matter and the laws and principles that control the action of the natural

forces by which we are surrounded and acted upon. From the prominence heretofore given to the first two members of the quadrivium, the ambition of teachers has been (until lately), almost entirely directed to them, and if the whole mass of instructors are considered, there is a general ignorance respecting the last two members.

Set before the teachers of almost any series of schools below the high schools a few plants or animals outside of the commonest forms, and ask them to identify them, or to tell something of their life-history, or call upon them to perform a simple experiment in chemistry, and a large majority of them would be obliged to confess inability.

We have stated that the elective system was introduced in response to a popular demand, and that this demand was because of public belief in the value of scientific training. But the elective system should be sparingly applied to our public schools, because in the nature of things the selection is likely to be too much left to the pupils who are not competent judges as to what courses of study are likely to be most useful or desirable for them. The relative value of studies in life is a question demanding for its solution the widest experience and the best judgment, and it is absurd to relegate it to the average school boy or girl, to whom it is likely to be left by the parents.

In the nature of things there must be for each community, depending partly on the amount of culture already possessed, a scheme of study best adapted for the average citizen, and this is the scheme that should be used. Special instruction should not begin till the general foundation has been laid, that it is the particular function of the public school to lay, and to which it should be limited.

The natural order of instruction in science may be termed a centrifugal one, beginning with those things the pupil is in immediate contact with, according to which the pupil is to be regarded as standing in the centre of ever widening spheres of knowledge, which represent the universe, learning first the relations of the things next to him, such as the map of his own city or district, then of his state, then his country, and in the same manner he would study first the plants and animals that belong to his locality, and then proceed outward to those of the world in general. Biological knowledge differs in one essential point from chemical, in that the first depends more upon careful observation, and does not quite so much require for its comprehension the exercise of the power of abstruse reasoning. It is therefore better adapted to be introduced into study schemes at an earlier age than chemistry, and it is admitted by all teachers who have tried it that biology is unequalled as a means of interesting the youngest child in the exercise of the powers of observation, which are among the faculties of the child first developed. Abundance of natural objects can be found even in a large city for this purpose. Such instruction is of course, or should be, largely independent of text books, though the judicious use of text books is of great value in handling large masses of pupils, which is an ever-present condition in our public schools.

The practical deductions the writer would draw from the course of reasoning, briefly outlined above, is:

1. That the Latin and Greek languages are now so far removed from our modern life that they should not be taught in our public schools that are supported by public taxation.

2. That a knowledge of the fundamental principles of chemistry and biology are of equal value with a knowledge of language or of mathematics.

3. That teachers who are ignorant of the fundamental principles of chemistry and biology are not competent teachers in our public schools.

4. That systematic efforts should be made by school boards to furnish schools with apparatus and specimens to illustrate these two branches of knowledge, so that they can be taught from the standpoint of personal acquaintance and experience, and not merely from text books.

The writer is aware the above ideas are not, broadly speaking, new; but they are pertinent to the struggle which began about thirty years ago, and which is far from being fully decided. Some of our public institutions of learning have already adopted study schemes more or less in conformity with the plan above outlined, but many more have not, and occasionally some take a backward step. A steady pressure is required to secure that progress, which in this as in other matters is essential to the welfare of our country.[1]

[1]Since the above was written, a symposium has appeared in the "Forum," for September, 1891, which is an important contribution to our literature on the subject. Rev. Henry A. Coit speaks for the classicists, and David S. Jordan for the scientists.

CURIOUS FORMS OF CHIPPED STONE IMPLEMENTS FOUND IN ITALY, HONDURAS, AND THE UNITED STATES: GEOGRAPHICAL ARRANGEMENT OF PREHISTORIC OBJECTS IN THE UNITED STATES NATIONAL MUSEUM: EVIDENCES OF THE HIGH ANTIQUITY OF MAN IN AMERICA: EXHIBITION OF JADE IMPLEMENTS FROM MEXICO AND CENTRAL AMERICA: EXHIBITION OF GOLD ORNAMENTS IN THE UNITED STATES NATIONAL MUSEUM FROM UNITED STATES OF COLUMBIA: INVENTIONS OF ANTIQUITY: EXHIBITION OF OBJECTS FROM THE UNITED STATES NATIONAL MUSEUM. By THOMAS WILSON, Curator Prehistoric Anthropology, United States National Museum, Washington, D. C.

[These several papers by Mr. Wilson will be printed in the Smithsonian Reports.]

A LINGUISTIC MAP OF NORTH AMERICA. By Major J. W. POWELL, Bureau of Ethnology, Washington, D. C.

ON BONE, COPPER AND SLATE IMPLEMENTS FOUND IN VERMONT: ON A COLLECTION OF STONE PIPES FROM VERMONT, WITH EXHIBITION OF SPECIMENS. By Prof. G. H. PERKINS, University of Vermont, Burlington, Vt.

SOME ARCHÆOLOGICAL CONTRAVENTIONS. By GERARD FOWKE, Bureau of Ethnology, Washington, D. C.
[This paper will be printed in The Anthropologist.]

PREHISTORIC BOWS: BOW STRETCHERS. By Prof. EDWARD S. MORSE, Salem, Mass.
[These papers will be printed in the Bulletin of the Essex Institute.]

RACE SURVIVALS AND RACE MIXTURE IN GREAT BRITAIN. By W. H. BABCOCK, Washington, D. C.

STUDY OF AUTOMATIC MOTION. By Prof. JOSEPH JASTROW, University of Wisconsin, Madison, Wisconsin.

THE IMPORTANCE AND METHODS OF THE SCIENCE OF COMPARATIVE RELIGION. By MERWIN MARIE SNELL, Secretary to the Rector, Catholic University of America, Washington, D. C.

STONE DRILLS AND PERFORATIONS IN STONE: EXHIBITION OF SPECIMENS. By ATREUS WANNER, York, Pa.

GAMES OF TETON DAKOTA CHILDREN. By Rev. JAMES OWEN DORSEY, Takoma Park, P. O , D. C.

AN ANCIENT HUMAN CRANIUM FROM YUCATAN. By Prof. F. W. PUTNAM, Cambridge, Mass.

SECTION I.

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ADDRESS

BY

PROFESSOR EDMUND J. JAMES,

VICE-PRESIDENT SECTION I.

THE FARMER AND TAXATION.

Questions of taxation have played a prominent part in the polity of English-speaking communities for many centuries, and they have not been without importance in the history of other civilized countries as well. A history of English taxation would be in no small part a history of the English people itself.

It was a quarrel about taxation between the nobles and King John which led to the granting of the Great Charter, and thus planted the seeds of modern constitutional government. English liberty indeed has been developed chiefly in connection with disputes about taxation. Charles I owed the loss of his throne and of his head largely to his determination to levy such taxes as he pleased without consulting the great men of his realm. English obstinacy in regard to the principle of taxing the colonies led to the American Revolution and the disruption of the British Empire. It was at bottom a question of taxation which led to the French Revolution, and the turning and overturning of Europe which has hardly ceased even now. And the history of this century on the continent shows how fundamental tax questions are to the welfare and prosperity of modern nations.

Of late the question has become of even more importance, and has acquired a very different aspect from that of former centuries. The disputes about taxation were, down to a recent date, largely of a political nature. They turned, not so much on the amount of the tax or the manner in which it should be levied, as upon the point who should say whether it should be levied at all or not.

The rulers or ruling classes tried to keep the whole question within their own control, and those who were opposed to this were trying to get the right to vote or refuse taxes. Now every civilized country in western Europe and America vests the right to say what taxes shall be levied and how they shall be levied in the people or their representatives. It is accepted as a definite principle that the people is the sole source of the authority to determine what taxes shall be levied.

We have indeed always had that principle accepted in this country, to a greater or less extent and in all its fulness, ever since the Revolution. People thought formerly that as soon as that principle was accepted tax problems would be solved. But it did not take long to find out how great an error this notion was. Hardly had the principle been accepted as a part of the fundamental law of the country when the representatives of the people found out that they were only at the verge, so to speak, of the question. The political side of the problem had been settled to a certain extent, but that only left room for the economic aspect to appear in sight, with a vast array of the most difficult questions. It soon became evident that under the systems of taxation in existence some people paid more than they ought to, and some paid less. Some classes were taxed but lightly or not at all and others very heavily. Then began the fight between the classes; between those exempted by law and those subjected by law to taxation. This conflict was slowly fought through, and now in nearly all civilized countries there are few classes exempted by law from taxation. But it was soon found that it was not necessary to exempt by law in order to take advantage of circumstances in such a way as to materially lighten one's burdens. Then began another struggle between the various classes as to which could shift the burden of taxation more completely, under the forms of law, to the shoulders of the other. The town was arrayed against the country, the producer against the consumer, the rich against the poor, the laborer against the capitalist, etc. We are still in the thickest of this fight, and there is no sign of an end to it. It is raging in all countries alike. Our tax problems are not very different in some of their most important features from the tax problems of England, France and Germany, and each of these countries can learn something from the experience, the successes and failures of the others.

The problem is all the more difficult because, even if all parties were willing to do exactly the fair thing, we should still find it difficult to determine exactly what the fair thing is. Where you can not obtain common consent as to what is fair and proper, we need not expect that private individuals will relax their efforts to get exemptions, and make laws under which they can escape what others may consider their fair share of taxation.

The matter is destined to become more rather than less important, and that from several reasons. In the first place the amount of money to be raised by taxation is destined to increase pretty steadily, if not very rapidly. This fact, of course, makes a bad system of taxation become worse and worse with every increase of the amount. If, for example, we had in this country to raise only a small sum for public purposes, say ten million dollars in all, for federal, state, and local governments, it would not matter much how we raised it. We might have an income tax on all incomes over ten thousand a year, or on all incomes of less than that, or a uniform tax on lands irrespective of their value, or even on polls; and while it might be very unequal, yet the whole amount would be so slight that it would not be worth while complaining about it. Even such a sum as a hundred million a year could be raised very easily by almost any system of taxation. But when you want to raise seven hundred millions it is a very different matter. A system of taxation which would yield a small sum becomes absolutely insupportable when you attempt to raise a large sum by it.

There are some theorists, it is true, who maintain that all the revenues necessary for public purposes could be raised easily by a land tax, or by an income tax, or by an excise tax. Such people have given little study to the organic nature of the state. In determining how much of a burden an organic body can bear, you must consider not only the weight itself but also its distribution. Take a soldier, for example. Would you measure the burden which he could carry in the field by the amount he could drag in the shape of an iron ball attached to one of his feet, or the amount he could carry in one hand, or suspended from one finger? Of course not. Every one recognizes that a load which would tire a man out completely in a few hours if placed on one part of the body can be carried for an indefinite period if only it be properly distributed. So with taxation. Any single tax presses down and destroys or tends to destroy some one part of the economic body.

Increase it and you not only destroy that part but, by sympathy, the whole body economic. Given a system of taxation then, which will yield a certain revenue easily without injuring any part of the body economic, if you double the amount to be raised, you will in all probability make the system absolutely insupportable.

Now this is exactly what we have done in this country. We have in essence the same system of taxation which was in vogue a hundred years ago. Indeed we may say that in all its most important features it is the same as was adopted in England in the time of Queen Elizabeth, for our ancestors brought it with them and adopted it almost without change when they settled the country. In the meantime our industry has changed, our agriculture has changed, we have changed our style of dress. We wear different hats, a better boot and shoe; we drive a better horse, milk a better cow, fatten a better hog, have invented a new plough, invented and utilized the railroad, steamboat, mowing machine, reaper, self-binder, etc., but we stick to an antiquated system of taxation which was not very good at the time it was adopted and has become worse ever since. If we were willing to abolish the public school system entirely, give up trying to improve the roads, starve the inmates of our jails and almshouses, tie up our insane to a post until they die of starvation and neglect, go back to fourteenth century systems of sanitation, abolish universal suffrage, and set up a class of nobles and kings to rule over us, perhaps we could get money enough out of the community to serve such public purposes as would then be necessary by the system of taxation which we now have. I take it, however, that we are not going to do any of these things. On the contrary, we propose to have better schools, better roads, take better care of our poor, be more reasonable in our treatment of the insane and criminal classes, establish better conditions of public health, do more to develop our industries,—in a word, we propose to advance and not decline in civilization. All this will require more money than we have now, and a system of public revenue must be established which will not only enable us to raise the sums at present demanded but very much larger sums, and at less cost of effort.

Think for a moment how enormously the expenditure for public purposes has increased of late years in all civilized countries. The ordinary expenditures of the Federal Government for the decade 1791–1800 were about four millions of dollars. For the decade

1870–1879 it was more than forty times as much; while the population was only about twelve times as great. In the state of New York the amount raised by taxation rose from twenty millions in 1861 to fifty millions in 1870; in Massachusetts, from eight to twenty-two millions in the same period approximately; and in Ohio, from eleven to twenty-two. In the fifteen years from 1860 to 1875 the total amount raised by taxation rose in Baltimore by 110 per cent; in Boston, 241; Brooklyn, 313; Chicago, 1445; Cincinnati, 377; Detroit, 384; Louisville, 318; Milwaukee, 326; Newark, 558; New York, 430; Philadelphia, 317, etc. For fourteen large cities the amount of increase was 363 per cent, while the population increased only seventy per cent. Now it is plain that a tax system which might have been at least bearable in 1860 was in all probability out of all reason in 1875, when nearly four times the revenue had to be raised by it.

Taking all the cities in Massachusetts, they paid six dollars per head in taxes in 1861 and over seventeen dollars in 1875. The city debts had increased from less than eight dollars per head to over fifty-four per head. Even if we take the period after the war, from 1866 to 1876, and take the average of 130 cities in the United States, including therefore the smaller ones also, it will be seen that the taxes rose from sixty-four to one hundred and thirteen million dollars. They have not declined since, but have all risen at least as rapidly as the population.

This phenomenon is not by any means confined to our own country but is quite as noticeable abroad. The expenses of Vienna rose from twenty-seven to sixty-seven million francs in the years, from 1865 to 1874, Breslau from four to eight, Florence from nine to twenty-four, Berlin from eighteen to forty-six. Paris rose from eighty-three to one hundred and ninety-six million francs in ten years. Thirty-two cities of Prussia increased their taxes eighty-three per cent in seven years.

A moment's reflection will convince any of you of the enormous increase in these burdens, even if you did not have these figures.

You all know that the expense for schools has become enormously greater than formerly. Every country district must now have its school taught from five to six months in the year by a teacher who gets on the average nearly twice as much as two generations ago. Every little village must have its system of graded schools, and if it gets a trifle larger, must have its high school. We are

now calling for manual training in the schools, and we are no longer satisfied with the horrible accommodations for teacher and pupils which used to satisfy our fathers. Our poor houses must be at least half-way decent places, our jails are vastly improved, etc. In a word, our expenditures are vastly greater, and consequently the sum of money to be raised by taxation. As a result the revenue system has broken down, and there are loud calls for a better one.

Now in deciding upon a system of public revenue, two things are to be kept in view. We must first of all find out where the wealth is that we wish to reach, and, second, we must then adopt the best system we can devise to find and tax that wealth. There is no use of adopting specific taxes unless there be something to be taxed.

Now here is just the difficulty in our present condition. Our tax system does not correspond to our industrial conditions. It was devised in all its essential features over three centuries ago, and has undergone little change. If we except the indirect taxes like customs duties, our present system is based on the idea that the chief wealth of the country is in its agricultural districts, in its farms, and consequently it is adapted to reach the main elements in such a condition of society. But nothing could be farther from the truth. It was so a century ago, but has long ceased to be so.

In 1790 there was no railroad in the country, scarcely any banks, few trades, little manufacturing, scarce a dozen corporations in the whole country, no very large cities, and ninety-seven per cent of the people lived in the country. What wealth there was, was in the country—in the farm, and land, and farm products. A system of taxation based on this fact worked fairly well.

How is it now? Where is the bulk of the wealth in this great country of ours? It is no longer in the country; it is in the cities, in and around which nearly half the population is aggregated. It is no longer in agriculture; it is in manufacturing; it is in banking; it is in railroads; it is in gas companies, in street-car lines, in merchandising and trading—everywhere but in farming. The earnings of the railroads of the country during the year 1888 were over one thousand millions of dollars. We have no reports as yet on the earnings of gas companies, electric light companies, telephone companies, street-car lines, telegraph companies, express companies, sleeping-car companies, manufacturing corporations, standard oil monopolies, cotton-seed-oil trusts. They mount up into

the hundreds of millions every year. The profits of trade in the agricultural product of the country alone amount to more than the total value of those products only a few decades back. In a word, the wealth has been steadily flowing away from the farms and into other forms.

This has come about in two ways: first, by the natural increase of manufacturing industry and of commerce in an age of steam and electricity, which could show relative increase of capital unused in those branches; and, second, by the actual fall of late years in all farm values in the old and settled communities incident to the opening up of new fields, which are asked to compete in the world's market by the cheapening of transportation in railway and steamship service. Not only Dakota and Montana compete in London with the Pennsylvania wheat, but also India, Russia, and even Africa. There has been a great fall of late in the value of farm staples in the world markets, which has depressed the value of farms in all the settled countries, in England, France and Germany, as well as in our eastern states. There are no signs that these prices will go up again, at least in your day and mine.

Africa, South America, India, Russia and Australia will be opened up faster than the demand for breadstuffs will increase, and you may be sure that Europe will not pay us high prices for our surplus wheat and corn when it can get cheaper supplies elsewhere. We need expect, then, no recovery in farm values so far as these depend on the price of staple commodities.

In examining this question of taxation, then, let us impress upon our minds several points: first, that we cannot hope to get money where it is not, no matter how good our system may be; second, that the wealth of the country is no longer in its farms; third, that the present revenue system is based on that supposition, and that consequently our whole revenue system must be radically changed to bring it into harmony with our modern industrial conditions.

No mere tinkering or pottering around with existing taxes is going to help. We must make up our minds to go to the root of the matter at once. Recognize that if we wish revenue we must reach the place where it is, and not try to get from it where it is not.

Before proposing our remedy it is desirable to glance at our present system and its effect. We have already seen that it is inadequate to meet the demands we are making and shall make upon it. It is simply impossible to get adequate revenue from it.

There is, however, another reason why our present revenue system is unsatisfactory besides the mere reason that it cannot meet the heavier demands upon it, *i. e.*, than its insufficiency to get the necessary revenue; and that is, that, owing to the great changes in our industry it has become grossly unjust.

We may characterize the system as a whole as the general property tax system, *i. e.*, the effort is made to ascertain the valuation of the entire property belonging to every taxable person, and then to collect a certain per cent of that valuation for the use of the public. Even if it were possible to ascertain such value, and collect the tax levied upon it, the system would be a grossly unequal one, and undesirable from many points of view. It would tax, for example, the thrifty farmer who had accumulated from his savings a sum sufficient to purchase a small farm in proportion to his thrift and savings; while it would let the extravagant lawyer or physician who makes thousands of dollars every year and lives it all up, go scot-free of all taxation. All those classes who use up their income as they go along would escape taxation, while those who save and invest it in some form of property would have to bear all the burdens of taxation. It would, in a word, discourage savings and encourage waste. Such a tax makes no distinction between the people of small property and those of large means.

The true principle of taxation is not every one in proportion to his property, but every one in proportion to his ability; and ability is not measured by possession of property alone, since a man of large means may better afford to give a larger sum than a person of small means a small sum. A general property tax, moreover, takes no account of whether the property is available for purposes of income or not. A person is taxed upon what he has, irrespective of the fact whether he can get anything out of it or not. And so I might go on and show how unequal and wasteful such a tax is, even if it could be fully assessed and collected. But the fundamental objection to it is that it can never be assessed and collected. To make it even approximately complete you must rely on the declaration of the taxable, that he has given a full and true list of his property. A portion of this property can, of course, be seen, such as houses and lands and furniture, implements and tools, pictures, books, pianos, etc. But another class cannot be seen, such as stocks and bonds, notes, mortgages where owned outside the community, etc., and all other forms of immaterial rights. It

is impossible to assess these things except upon the personal declaration of the owner. Now everybody who has looked into the matter at all agrees, I believe, that this cannot be relied upon at all.

All tax commissions which have reported upon this point say that existing laws do not secure such a return. Taxables commit perjury by wholesale in such matters, and think nothing of it. How much of this sort of property escapes taxation can be seen from examining the tax books and reports of any of our leading American cities. We have, of course, no adequate statistics of the relative value of personality and real estate for any country or part of a country. No one, however, estimates the value of the personal property held by the inhabitants of a great city at anything less than the total value of the real estate, and it is my opinion that it is much more. According to the report of the tax commission of the state of New York in 1871, the real estate assessed in that state for the years 1869–70 was more than three and one-half times as valuable as all the personal property owned by citizens of that state. In the city of Brooklyn the valuation of real estate was over ten times as much as that of personal property; Rochester over six times; Buffalo and Albany over four times as much. In the city of New York it was nearly two and one-half times as much. One county in New York reports real estate worth seventy times as much as all the personal property owned by its citizens. Massachusetts, which has perhaps the best enforced law of this kind, does not reach over two-thirds of the personal property in the opinion of its tax collectors. Connecticut misses forty per cent. One may almost say that in the large cities much the larger half of the personal property escapes taxation altogether. That means, of course, that the other forms of property are disproportionately burdened. The total personal property of the entire State of New York was returned in 1870 at $434,000,000. Why, there were at that time, in the city of New York alone, twenty-five individuals who together probably possessed that sum. The value of the steam railroads in that state in that year was $300,000,000. In a debate in the constitutional convention of 1867, Mr. Pierrepont of New York said that he could name thirty individuals in New York City whose combined personal property exceeded the whole assessment of the State for that year by a very large sum The whole personal property assessment of the city of Brooklyn

against private individuals for the year 1867 was less than ten million dollars. Possibly it had a single citizen who was worth that amount.

But why multiply examples. They are like the sands of the sea for multitude. Now, under any such a system as this, those classes who have comparatively speaking little personal property, are the ones who must bear the burden of taxation. Who are they? Speaking generally, the farmer in the country and the small man in the city; the laborer who has saved up money to buy him a little house, and whose whole property is, therefore, open to the assessor; the farmer who has put all his money into his farm. Who profits by it? The man of means who invests his money in railroads, bank stock, gas companies, etc.

The objection which I have been urging against the general property tax which forms the backbone of our system would apply more or less to the system at all times; but it is becoming more and more potent as time goes on, owing to the fact above mentioned that the proportion of wealth in an immaterial form, such as stocks and bonds, is steadily increasing. I hardly need to dwell upon this point. You all know how enormously the value of railroads in this country is increasing. Nearly all of it consists of immaterial or personal property; or where it consists of real estate, the value of such real estate cannot be measured by the ordinary standards, but it possesses a value growing out of the peculiar business of the railroad which is rarely reflected as it should be in the tax books. The railroad is the most striking example, but not even it is so important as the aggregate of similar undertakings in other lines of business. Consider for a moment the stock of express companies, telegraph companies, telephone companies, gas companies, electric lighting companies, joint stock banks, manufacturing companies, etc. Indeed, the marked tendency of capital to-day is to assume the corporate form, owing, among other things, to the ease with which it escapes taxation. This is a phenomenon of comparatively recent date. The corporation first became a prominent feature of our industrial life, as of that of other countries, since 1850. There were, of course, many corporations before that date, and one or two flush periods when nearly everybody took a hand in them, but they were confined to few departments of industry. After 1850 they grew rapidly. In Germany, for example, only fifty-four are known to have been

founded before 1850, while one thousand one hundred and fifty have been formed since that time. In Austria there were in 1857 only fifty-eight in all, but they had risen to seven hundred and eighty-one by 1873. England and America are, however, the classic lands for the development of corporations. In 1844 there were one hundred and nineteen in England, but they had increased to two thousand five hundred and forty-nine in 1862, and by 1886 over twenty-five thousand had taken out charters, though many of them had wound up their affairs, so that only eleven thousand were in operation in that year, with a paid-up capital of over three thousand millions of dollars.

In this country we have accurate statistics only for a few of the States, and then only in regard to certain formal facts. In Massachusetts, from 1852 to 1863, anywhere from ten to fifty companies were formed each year. The next three years averaged three times as many; then came a long period up to 1880 in which about seventy-five to one hundred were established each year, and since 1880 an enormous number have been formed, rising to two hundred thirty-three in 1889. The total capital of these companies aggregated upwards of $300,000,000. In the State of Ohio in 1889 over three hundred corporations for manufacturing purposes were organized, and the average for the last ten years has been over two hundred. Now all these things mean, of course, that property of the community is all the while taking on more and more the personal property form, is leaving the country for the city, and that any general property tax system is becoming more and more unequal owing to impossibility of keeping track of it. With every passing year, then, our present system is becoming more and more untenable, and yet we are not ready to break with it.

There is still another circumstance which should be considered in this connection before leaving it, as having a special relation to the farming classes, and that is the rapidly changing proportion between town and country population. It is easier to avoid personal property taxation in the city than in the country. And thus from this reason also the burden of taxation becomes more unequal. In 1790 only three per cent of the population of the United States lived in cities of 8,000 and upwards. In 1800 (using round numbers) four per cent, in 1810 five per cent, 1830 seven per cent, 1840 nine per cent, 1850 thirteen per cent, 1860 sixteen per cent, 1870 twenty-one per cent, and in 1880 twenty-three per cent.

It is not yet known exactly what the new census will show in this respect, as the population of all cities above 8,000 has not been given. But some figures have been given to show that this tendency has steadily increased. In 1880 there were twenty-four cities in the United States with 75,000 inhabitants and over, while in 1890 this number had increased to thirty-four, *i. e.*, while ten years ago about thirteen per cent of the people of the country were living in cities of 75,000 and over, to-day over sixteen per cent are to be found in such cities. The increase of these thirty-four cities, without counting New York, has been almost forty-five per cent, while the general increase in the country as a whole has not exceeded twenty-five per cent. Reports have been also published of forty-two other cities having a population of 20,000 or over. The increase in the seventy-six cities over the population of the same cities in 1880 was about forty-eight per cent. The census may be faulty, but I take it we shall have to admit that growth of the cities has been much more rapid than that of the country. This being so, it still further tends to increase the burdens of those classes who can least easily conceal their property under a general property tax system, viz., the farmers.

The rapid growth of the cities, in many cases at the expense of the country, tends, moreover, to leave a continually increasing burden of expense upon the shoulders of the rural districts, which tends to overburden the latter still more.

Under our system of taxation, then, the farmer, using that term for the country districts in general, is at a disadvantage in several respects. In the first place, as we have here seen, our method of obtaining public revenue by taxation touches chiefly that form of property which is visible and cannot escape the eye of the tax assessor or tax collector; while that which can be hidden or known only by a general system of registry, such as mortgages, bonds, stocks, etc., practically escapes taxation altogether. Now the farmer has a larger proportion of his property in this form than any other class. If he is thrifty he can buy more land, put up a better class of buildings, get a better breed of stock, use better machinery, etc. Every improvement in his condition, in a word, reflects itself in something visible about the farm, and thus subjects him to heavier taxation. It is very different with inhabitants of the cities. A wealthy man, of course, occupies as a rule a better house in a dearer neighborhood than a poor man, and to that

extent pays more taxes; but as his wealth increases his house does not necessarily grow better. His scale of living may not increase proportionately. A millionaire is quite as likely to live on as great a scale as one who has ten times the property. As a result, the visible forms of wealth do not increase as rapidly in the case of the wealthy city man as in the case of the country farmer. More and more of the property takes the form of mortgages, bank, railroad, and manufacturing stocks and bonds. All these things escape the eye of the tax assessor, and to that extent relatively lighten the burden of the wealthier classes.

It has been proposed, indeed has been done in many states, to make every man swear to the truthfulness of the returns, and to provide adequate penalties for false returns. Experience shows, alas! that men will swear falsely by the wholesale and really seem to think little of it. Nor would any American community favor the establishment and enforcement of penalties which would really accomplish anything in this direction. As long, therefore, as this system remains we may expect to see the farmer unjustly burdened, simply because, as conditions are, a larger portion of his wealth is in such a form that it cannot escape taxation.

The country districts are, however, at a disadvantage in another direction. Owing to their declining wealth and population they must either continually advance the tax rate or they must be content to see the public institutions of the community go slowly backward. The number of people in the country as compared with the city is, as we have seen, steadily decreasing, *i. e.*, the cities are growing steadily larger, and embracing a continually increasing proportion of the population. This means, of course, either that the burdens for the support of schools and other public institutions will grow heavier and heavier, or that they shall not advance, or, indeed, shall retrograde. It is no uncommon sight to see the schools gradually deteriorating in the rural districts. It is not merely true in Pennsylvania, Ohio and Illinois, but even in the New England States, that classic land of education, where all classes take a pride in the liberal support of all public institutions, such as the school, the church, the public library, etc.

This is a disadvantage not merely for the country but for the city as well. Once let the rural school and other similar institutions become thoroughly low in character, and more and more people will wish to leave the country, and the stream into the cities will be

swollen still more. American people will not be content to live permanently in a region where all the institutions which make life worth living are gradually going backwards.

It is for the interest of the whole nation then and not merely for that of the farmers, that the attractions of country life shall be increased and not diminished. The existence of good schools, churches, roads, lyceums, libraries and other means of education throughout the country districts is necessary to the welfare of the whole community. Our great cities live upon the country in more senses than one. They are dependent upon it not merely for the material means of living, such as grain and meat, but for population itself. Statistics show that the death-rate in cities is rather higher than the birth-rate, *i. e.*, if the cities could not draw upon the country they would soon begin to decline in size. Such being the case, it is of the highest importance to the cities, and to the country as a whole, that those classes which feed the cities, and give them the very bone and sinew of their existence, shall have the very best opportunities for an education. In the interest of the rural districts themselves the same thing is demanded. The draining away to the cities of the best blood of the young generation inflicts a continual loss upon the country. And yet if the attractions of country life on its intellectual side cannot be increased we may expect to find this loss a continually increasing one. At the very time, then, that farmers ought to be making increased expenditures for public purposes we find their means of making such expenditures curtailed.

But there is another aspect to this problem which must be considered a little more at length before passing on to consider remedies though I have already touched upon it and shall mention it again. The whole industrial development of this and other countries of late has been along lines that affect the farming classes most deeply. We have been expending enormous sums of money to construct railroads in order to open up new fields.

We have revolutionized the grain market of the world in the last few years. This means of course that the conditions of farming have been revolutionized. Take for example the wheat market. Only a few years ago the wheat market was essentially a local one. Farmers could be reasonably sure of finding a sale for their wheat at a remunerative price. After the railroads opened up the great fields of northern Dakota, a great revolution took place.

I do not mean to say that this is not on the whole a good policy. It is at least in all probability an unavoidable policy and we must put up with it perhaps for some time to come. But it is certainly not fair or just to expect the farmer, the individual farmer, to bear the whole burden incident to the pursuit of a policy which on the whole may be of value to the country. The country has no right to saddle the whole cost of making great experiments upon any one class of the population.

The farmer, then, suffers under the changes incident to the continual advance of the country. He suffers from the growing population of the country, and he suffers from the incidence of a system of taxation which did well enough a century ago but is now as antiquated as the plough or wagon of that time. What shall be done to help him?

In the first place trying to doctor the present system here and there, as I said before, will not help him. We cannot materially improve our present system of taxation by little changes introduced here and there. I take absolutely no stock in the desirability of attempting it, or the hope of achieving success if it were attempted. A general property tax, such as we have now in most of our American states, I regard as a hopelessly inefficient one, and highly unjust in all its effects. Even if it were possible to do anything with it, I should be opposed to retaining it, as it is, in my opinion, fundamentally vicious in such a condition of society as ours. It is moreover impossible to do anything with it, because it cannot be enforced. It is useless to try to ascertain all the property which a man possesses in our society. It was not possible for the tax gatherers in the Middle Ages to do it, when they could apply the thumb-screws *ad libitum* as an assistance to the memory of forgetful taxpayers—how much less to-day, when no jury in the United States would convict an ordinary citizen of perjury because of false returns to the tax assessor. When it is possible for a man like one of the Vanderbilts to swear that he has only $100,000 in the world which is liable to the general property tax, and it is impossible to prove the contrary in the case of such a well-known person, what is the use of trying to reach the property of the ordinary citizen by such means? I think I am fully within the truth when I say that no one who has made any study whatever of tax questions thinks that a general property tax upon personal property can be collected. The scientific students of tax-

ation all agree, I think, to a man, that a general property tax of this sort is a relic of mediævalism, and should be abolished as soon as possible.

The farmers of all classes ought to be opposed to such a tax. Why? Because, besides the reason already given, the effect is more injurious to the country than to the city. It is easier to collect such a tax in the country, because people in the country know more, as a rule, about the affairs of their neighbors than those of the city. It would be impossible for a farmer to have any great amount of money invested in mortgages, etc., without it coming more or less to the knowledge of his neighbors, and hence to the ears of the assessor. In the city, on the contrary, the individual is lost in the crowd. The result is that as soon as the farmer has any considerable funds in this form there is great temptation to move to the city, and hence another inducement is added to the already too long list which tends to drain the country of its very best elements.

The taxing of mortgages and money at interest is another subject which has attracted a great deal of attention. Who pays this tax! Some authorities say the borrower, some say the lender. Of course if a tax be levied upon money now invested in mortgages, and collected from the owner of the mortgage, the money-loaner must pay it. But how about the new mortgages? If it were possible to reach absolutely all the money up for loan we might make such a combination possible by which the loaner would have to pay it. But as things are now, the bulk of the money escaping it altogether, even in those states where such a tax is nominally levied with many states which do not seriously try to levy such taxes, he must have large faith who believes that the money-lender must pay this tax instead of the farmer, whom he charges so much the more interest by reason of the tax. At any rate it is not an important element in this problem in my opinion. We must begin at the other end and try to reach quite a different class in the community. We can dispense with the tax on mortgages very easily if we reorganized our revenue system as we ought.

The farmer can be helped then, as I insisted at the beginning of my paper, only by a radical change in our revenue system—a change which will remove taxation from the place where wealth is not, and put it where it is. To do this we must use the state and national government. Speaking generally, his taxation must be

lightened and the income of local communities, particularly the rural districts, must be increased for public purposes. The lines along which this revolution must be made I shall briefly indicate. In the first place, farming property should be exempted from all taxation for state purposes. This has been done already in some of the states, in Delaware among the rest. In Pennsylvania, for example, the tax on real estate is solely for local purposes. The state does not levy any assessments upon real estate for state purposes. This may not seem a very considerable lightening of the burdens; but it is important, since when a man is loaded beyond his strength every decrease of the burden is of significance. In the second place, the state must come to the support of the local community, and that in two ways. It must distribute large sums to the communities for the support of local institutions, like the schools; and it must assume the entire expense of certain public functions, like that of justice, and especially the support of the unfortunate poor, such as the insane, the blind, idiotic, etc., as also the expense for penitentiaries.

The support of the unfortunate poor is something, which no local community can reasonably undertake, for it has not the facilities to extend such care to them as our modern humanity demands. All such people ought to be put in asylums and supported at general and not local expense. Nor can the local units afford to provide as they ought for the criminal classes. They are, moreover, oftentimes not at all responsible for the criminal character of the population, as the latter may have drifted in from other communities or indeed from other states.

The care of the unfortunate and criminal classes requires the employment of highly educated and specially trained people, whose services can not be commanded by localities, even if they could pay the expenses for suitable buildings, which as a rule they cannot. The expense of the courts might also be borne by the state to a very large extent. The existence of county courts, for example, does not accrue alone to the benefit of the people of the county, but quite as much to the people of other localities or indeed of other states, who may have occasion for any reason to claim their services in any action at law.

The support of schools is also a function in which not merely the local community is interested but all parts of the state as well. I think that every one must say that our farming communities are

not at present able to pay the expenses of really good elementary schools. It is, in a large proportion of the rural districts, impossible to find anything more than elementary schools. Yet there is no reason why the advantage of good high schools should not be open to farmers' children as well as to the children of city people. If there were good schools in the country, we should find that many people would stay there who now go to town as soon as they can rake and scrape the money together. The only way in which such school facilities can be offered is for the state to come to their aid in an efficient manner. In many of the states already a school fund is provided, the proceeds of which are distributed among the school districts. In some states this pays the salary of the teacher for six months or more in the year. In other places the state government raises by taxation a large sum, which is distributed in the same way among the school districts. In a few states, the state government pays a large share of the expense, wherever communities will establish high schools. Adequate educational facilities can never be obtained in this country until the state governments undertake to look after the matter themselves, and contribute handsomely to the support of good schools of all grades. It is simply impossible for the farming districts under existing conditions, to raise adequate sums for this and all other purposes which they must look after.

Another department in which the localities must be aided is in that of maintaining good roads. Since the advent of the railroads we have done next to nothing toward improving our local means of communication. Such abominable, horse destroying highways as exist in most of our American states you can not find in any other civilized country. The farmers waste as much money, time and horse-flesh in getting their crops to market over a few miles of our ordinary American roads as would suffice to take the crops around the world on a railroad or steamer. Local management and support of the roads, as we try to work it in this country, has always given poor roads in every country where it has been tried. All other civilized countries have gone over to a reasonable system, under which the leading roads of the state are made under the supervision of state engineers and at state expense; the roads which are merely county, are kept up by the county, while only the very subordinate roads, the paths across the fields, etc., are saddled upon the road district. The roads are, moreover, to-day of immensely

greater importance to the farmer than they were a century ago. In 1800 nearly all the products of the farm were consumed on the farm. To-day the bulk is shipped to market. The cost of transportation is largely a burden on the farmer. Any diminution in the cost helps him, and it also helps the inhabitant of the city; and while the latter profits by good country roads he contributes nothing to their support, but leaves the entire burdens of constructing and maintaining them on the farmers.

Local management of all these institutions, then, and the attempt to make the localities pay for them, lead to two things, relative overburdening of the farmers, and inefficient institutions. The general neglect of our country roads leads to the massing of the population along the railroads, placing them still more completely at the mercy of the railroad managers than they are now.

The thorough-going reform of our financial system means, however, more than the mere utilization of the state government in lifting the weight of local burdens. It means a further utilization of the federal government for the same purpose. Under the political system which we adopted a century ago we distributed the functions of that time among the national, state and local governments in a way which experience has shown to have worked very well down to a recent date. If the economic conditions of a century ago had remained the same until to-day, the system would be still as good as then. But the railroad came in to modify and change everything. Aided by the federal, state and local government, to the extent in many cases of building their lines for them, they have continued to increase in number and importance until they dominate our whole industry and government. Nothing can be done without their consent. No problem can be solved without considering the railroad. They have changed the centres of trade and industry. They have shifted the centre of agriculture. They determine more and more the lines along which industry and population must move. They have been built and are now building, not necessarily in places where the true interests of the country would have dictated, but oftentimes where ideas of private interest, caprice and fancy may have ordered. They have built up great sections of the country, it is true, but they have also ruined others. They have developed farmers on the icy plains of Dakota and on the burning sands of New Mexico, but have driven a race of farmers to the wall in New England, Pennsylvania, Delaware, etc. I

do not mean to say that this is not good. It may lie in the interests of the country to change the centres of industry. But when this is done by a national policy it is not fair to ask one class to bear all the burden.

Now we have given to the nation the most fruitful sources of revenue and to the community the heaviest burdens to bear. The defence of the country against foreign aggression has never been a very heavy burden, and it is destined to become lighter and lighter; but the burden of keeping up the educational institutions of the country, the load of keeping up the means of local communication by the system of country roads, the support of the courts open to all citizens of the United States, the support of the poor, the blind, idiotic, insane, etc., are heavy, and continually growing heavier. To the federal government we have given the right to resort to all sorts of taxation,—duties on imports, on domestic products, on incomes, on lands, on polls,—in fact every kind of privilege in this respect consistent with the practices of a free government, except taxes on exports. To the states we have, it is true, also given the right to levy all sorts of taxes except duties on imports and exports; but the industrial circumstances prevent us from resorting to the most fruitful sources, to those places where the real wealth of the community to-day lies. No state dare tax its domestic manufactures, for example, from fear that the manufacturers will move into another state. We cannot levy an income tax, for fear that the citizens will reside somewhere else. This practically keeps us from resorting to the most fruitful sources of revenue altogether. One may say, How is this different from the condition of things a century ago? If our fathers got along well then, why should not we now?

A century ago a state could resort to such taxes as it chose, because the impediments to changing one's residence or moving one's business were practically so great that nothing short of the very heaviest taxation could move one to try to avoid it by altering his location. To-day, on the contrary, thanks to the railway, there is almost no obstacle to living in one state and doing business in another. The merchant in New York city can live in Connecticut, New Jersey, or New York, or even Pennsylvania or Massachusetts, and still be in New York every day for business. The citizen of Wilmington can reside in Delaware, Maryland, Pennsylvania, or New Jersey. Of course under such conditions,

the various states have to be very careful about levying taxes, and the possibility of adopting taxes which a century ago were easy to use and collect is very much limited.

In a word, our financial system and our industrial system are no longer in harmony, and they are daily growing wider and wider apart. The bodies which have heavy public burdens have only limited financial resources, and those which have large resources have comparatively few functions. The places where the wealth is not are taxed; and those where it is are left untaxed. Now there are only three ways out of the difficulty. Either the functions of the federal government must be increased to correspond with the greater financial power of that body, or greater financial power must be conferred upon the local bodies by allowing them to tax imports from other states in order to enable them to adopt an excise system or we must collect those revenues for local purposes through the federal government which can be reached only through its agency. The first of these is undesirable; the second impossible, while the third is at once practicable and feasible.

If we would have a reasonable system of taxation we must entrust to each public body the collection of such taxes as it can most easily raise. Thus the tax on land can easily be raised by the local bodies, such as city, school district, township and county. The taxes on corporations which do business over a whole state, like the railroad corporations, cannot be collected by the local communities. Nothing is more ridiculous than for a township, for example, to try to collect a tax on a railroad which runs through it. If it assesses merely the value of the road-bed for what may be termed ordinary uses, the assessment is, of course, ridiculously low. If the local assessors attempt to assess such a part of the whole value of the road as the local part bears to the whole length of line, they have no means of compelling payment or of proving that their assessment is a fair or just one. The only sensible thing is to allow the state government to tax the railroad and divide the results of the tax among the communities in the state. The same thing is true of other sorts of taxes as well.

In the same way the collection of import duties is one of the most fruitful sources of taxation, and that whether you take a so-called tariff for revenue only, or a so-called protective tariff. No state or local community can collect these taxes, and yet to let these taxes go uncollected would be a very short-sighted financial

policy; since you can raise large sums by this device without injuring the country at all. Take, again, the whole line of manufacturing trust and similar organizations in this country, the Standard Oil monopoly, for example. Here is an excellent subject for national taxation. No state can reach it. It has practically withdrawn itself from state control, and as we make no attempt to control it by national means, it is practically untaxed. Now this is very foolish and unreasonable. What shall be done about it? No city or county or state can tax it. Shall we let it continue to go untaxed? By no means. We should tax it through the agency of the national government, and take the proceeds for local purposes.

We must no longer look upon the county government as opposed to the township government in matters of taxation, or the state to the county, or the federal government to the state, but upon all as part of one and the same system of government, to be used by the people in the manner and to the extent which its interest may dictate.

In a word, then, the solution of the financial difficulty in this country, as I look at it, is simply this: Let us use each part of the government, city, town, school district, county, state and nation, to administer those taxes which it can most easily manage, and then divide the proceeds upon such basis as experience may dictate to be the best. Briefly indicated, and only in the most general way, the land tax ought to be left to the ultimate unit—city, town, road, school, poor district, etc. The state ought to levy an elaborate system of corporation taxes upon such corporations as it can efficiently reach; and finally, the nation ought to levy the indirect taxes, such as excise and customs duties, and such other taxes as circumstances may show to be desirable, such as taxes upon the great combinations of capital which extend their operations over the whole country, and possibly also, upon incomes. We should take the proceeds of such taxes beyond what may be necessary for an economical administration of federal affairs, and utilize them for local purposes. The states should use the funds derived from the taxes administered by itself, partly for the performance of a larger range of functions, partly in assisting in the performance of local functions, as in making roads, etc., and partly in distribution among local units for local purposes, as schools, etc.

I am all the surer that this is the proper solution, as it is the one

which other modern nations situated somewhat like our own, have found it necessary to adopt. As said above, the problems of modern taxation have come up in all nations in a very similar form. Local taxation has assumed an importance hitherto unknown, and the relation of the farming class to other classes in this matter has been a troublesome one. England, France and Germany, which in their economic conditions most resemble our own country, have all found it necessary to resort to some such plan as that here outlined.

No amount of patching is going to help us in this matter. No attempt to strengthen the hands of local tax assessors or tax collectors is going to afford any permanent relief. The more tax commissions we have which give such advice as the late ones have given us, the more money will be wasted, and the time will be the more delayed when a reasonable system will take the place of the present antiquated patchwork.

Before closing, I should like to revert again to a point already mentioned, to touch upon another phase of the question which I regard as even more fundamental than that of taxation, important as is the latter; and that is, the whole economical condition of the farmer as compared with the other classes in the community. I touched at the beginning of my address upon the revolution which the modern system of transportation had effected in the condition of the farmer; how it has brought into competition with him not only the farmer of the Mississippi Valley, but has planted a competitor on the slopes of the Pacific; nay, even opened up Africa and Australia as competing territories. The farmer was formerly assured of a certain even though it were a small market. His market is now large but very uncertain.

The farmer feels the burden of taxation, in a word, largely because his economic situation has become an unfavorable one. The prices of agricultural products of the staple variety have gone down in the great European market upon which we rely to dispose of our surplus products. It looks very much as if they would never rise again, at least not for a long time to come. The settlement of Australia, of South America and Africa will more than keep pace with the wants of the world for breadstuffs; and until Russia, Asia, India, Africa, Australia and South America are so fully settled that they will consume their own food-crops we need not expect to see a rise in the price of the staples. No amount of bait thrown out

to European nations in the form of low tariffs is going to persuade them to take our corn and wheat at high prices when they can get Russian and Indian products at low prices.

Now if this be a true diagnosis of present conditions, what can the farmer do to be saved from being ground to powder between the upper and nether millstone; between a system of taxation, on the one hand, which leads the great accumulations of wealth relatively untouched, and rests chiefly on agriculture, and a world of economic movement on the other, which is knocking the bottom out of all staple products? My answer to the question, so far as the first point is concerned, is to reform your system of taxation; as to the second, make yourselves independent of the staples. Let us try to discover and utilize new products. We can no longer rely upon the old crops to keep us alive. We must discover new branches of agriculture. Perhaps it will be found, as in Germany, in the discovery of a sugar plant, or in the cultivation of tea or coffee, or a new textile plant, or something else. Now from what source have we to look for the introduction of such a plant or plants? Who can bear the initial expense of ascertaining by a long series of costly experiments what kind of soil and climate are best fitted to each new crop. Manifestly only the government. Hence the absolute necessity of the government experiment station, planted in every state, and endowed on such a scale as will enable it to make the most costly and long continued experiments upon every new crop which seems to promise any hope of naturalization. We have been naturalizing men long enough. Let us now try systematic plans to naturalize every useful plant which is to be found in any other country. The federal government has begun this work on a fairly liberal scale. It should be your business as farmers to see that these appropriations shall be made on a still larger scale than ever, and that in each district in the state a careful examination of soil and climate by scientific experts shall be made, with a view of determining what new crops can be introduced into such places. In this way, you will find that the introduction of a new crop will go a long way toward solving the taxation and all other problems, since it will introduce prosperity where adversity now prevails and expanding agriculture instead of a declining one, etc.

Perhaps a word might not be out of place at this point as to the

work of the experiment stations themselves. I cannot help feeling that much of their effort has not been so economically applied as it might be. It is, of course, an interesting fact to know what the growing power of a pumpkin is, for example. How many tons a water-melon vine can lift in the course of a year, and similar items of information, may in the course of time, when all added together, produced valuable, practical results; but I cannot but believe that a much larger share of time and effort should be devoted to ascertaining the possible uses of the thousand-and-one forms of vegetable life around us. Man progresses but slowly. Of the thousands of plants which cover the face of the earth we have found use for comparatively few. They are mostly still ranked in the category of weeds, *i. e.*, useless or injurious plants. It has not been so very long since the potato was in this category. Now it is my opinion that every plant has some valuable use or other if we only knew it. It is preëminently the work of such scientific stations to enlarge the number of useful plants by such experimentation as shall test their applicability to one or another of the practical arts. He who makes two blades of grass to grow where only one grew before is a benefactor of the race. How much more a benefactor he who gives two useful plants instead of one. Who can calculate the advantage to humanity of the development of the potato or of the sugar beet?

The scientific experimental station, then, should give us new plants, naturalize those already known, and determine the best conditions for the cultivation of all kinds which may be made to grow in any given locality. The same thing should be done, of course, for animals as for vegetables. There is little doubt that in each state, for example, many plants could be profitably cultivated and animals bred which are practically unknown at present. The experimental station should work at these problems until they are successfully solved. I say at each station, for the station of Pennsylvania, or that of Illinois, or Ohio, will benefit Alabama only indirectly, since crops which will grow very well in the former states will not grow well in the latter, and many which might prove profitable in the latter would not grow in those states at all. Each locality must solve its own problems in this respect for itself. It has been found, for example, even in such a small country as Germany, that a beet which will produce a large quantity

of sugar in one part of the country, when taken to another loses its sugar very quickly. How much more would that be the case in such a country as our own?

Let us keep up our experiment stations then. Watch them closely, to see that they are at work at useful things, but support them liberally. See to it that the federal government, which has now begun the support of these institutions, shall deal liberally with them. Give them all the money they can wisely use. We shall find that that will be a great deal, and you will find that it will very well pay for itself.

The country at least to some extent. You are not in that condition. Even if you transfer to the state government many of the burdens which now rest upon localities you will not experience the same relief as such a State as Pennsylvania which in making such a transfer, shifts the burdens largely to the cities and corporations doing business in the city. You have contributed your share to the general prosperity of the country. You have helped to build the railroads across the continent, which being built have undermined the conditions of your prosperity. You have done your share in swelling the stream of national prosperity, which is now rolling on with such resistless sweep, rolling however away from you, leaving you stranded high and dry at one side. How are you to get a fair share of the results of national production for use within your territory? I see no way except to insist that the nation to which you have contributed to build up shall contribute also not to your downfall but to your upbuilding. That the nation shall tax those things which you cannot reach but which you have helped to make and hand over to you the proceeds to employ within your own boundaries. To some slight extent it is doing this, of course, in the support which is giving to your experimental station. But this is a mere drop in the bucket. You should have a portion of the proceeds of national taxation to assist in the support of your common schools and your highways, of your normal schools, etc., etc. The great and powerful states like Pennsylvania and New York, those which lie in the path of commerce across the continent like Ohio and Illinois and are thus enabled to tax the produce of the continent and as a matter of fact taxing your products in their transit can get along under the present system and continue to grow and wax strong, even though it be at a slower

rate than would be possible under a more reasonable system. But the smaller states and those which lie to one side of the course of national development must bestir themselves if they do not wish to slip back and be left far behind in the race. If they would not see their farms go back to the original state of wildness, if they would not have a howling wilderness take the place of many a smiling village and flourishing farm, you are the very people who suffer most grievously under the present system and you may be sure that nobody will help you if you do not help yourselves.

PAPERS READ.

MECHANICAL METHODS USED IN COMPILING DATA OF THE 11TH U. S. CENSUS; WITH AN EXHIBITION OF A MACHINE. By JOHN S. BILLINGS, Surgeon U. S. Army, Washington, D. C.

[ABSTRACT.]

THAT the data collected by the census for each living person, or, in systems of death registration, for each decedent, might be recorded on a single card or slip by punching small holes in different parts of it, and that these cards might then be assorted and counted by mechanical means according to any selected grouping of these perforations, was first suggested by Dr. Billings in 1880.

This suggestion was taken up by Mr. Herman Hollerith, and by him has been elaborated into practical shape the system which is now in use in the Population and Vital Statistics Divisions of the 11th U. S. Census, and which has been adopted for the compilation work of the recent Austrian and Canadian censuses.

For each individual living in the United States, June 1, 1890, as shown by the census schedules, the facts relating to sex, age, color, conjugal condition, birth-place, birth-place of each parent, occupation, number of children, etc., have been indicated on a piece of stout manilla paper $6\frac{5}{8}$ inches long by $3\frac{1}{4}$ inches wide, by punching holes in different parts of it. For each decedent during the census year, the same facts are reported, and, in addition, the cause of death and the month of death. The place of residence, by state and district, is indicated in like manner.

The number of subdivisions which can be distinguished in recording the different classes of facts in this way is very great. For example, in 48 spaces it is possible to record the distinction for each of 45,000 different districts, as is actually done by the gang punch system for the census. Two groups of twenty holes each will give 4,000 subdivisions in combination by twos. The present sized card is sufficient to contain 12 groups of 24 holes. Each of these 24 taken singly will give 24 subdivisions; taken by twos they will give 276; by threes, 2,024; by fours, 10,626, or a total of 12,950. A million of these cards weigh about 5,000 lbs., and occupy a space of about 192 cubic feet.

The cards thus punched are passed through machines in which an electrical connection is made by the passage of a metal rod through the cards

wherever a hole has been punched, and the currents thus produced actuate a series of small dials on which the number of the data is recorded. About 40 of these dials are usually used at once, each of which record a single class of facts; for example, the first dial may be set to count all males, or may be set to count all males under one year of age, or all white males under one year of age, or all white males born in Pennsylvania under 20 years of age, or all white male butchers in Pennsylvania whose mothers were born in Germany and who are between 25 and 30 years of age. If no record has been punched on the card for age, birth-place, etc., the machine does not record and the attention of the operator is called to the fact that the card is defective.

The machine not only records certain groups of facts on the dials, but has a series of assorting boxes which also have electrical connections by means of which the cards, as they pass through the machine, can be assorted into groups on any system required, as, for instance, into groups of ages, into groups of birth-place, or according to birth-place of mothers, or according to occupations, etc.

In the Population Division, after a little training, the average number of cards punched per day by each operator was 766, some punching 1,200 to 1,400 per day. In punching death records the work was a little slower, but ten clerks averaged over 1,000 per day each.

The accuracy of the work in punching by each person was tested at the beginning in what was called practice work, and no one was allowed to enter upon the work of punching until the percentage of error made in practice work had been reduced to the minimum. A certain proportion of cards punched by the clerk in his particular section was each day carefully compared and verified, and the number and character of errors made recorded and reported.

In the work of punching three classes of errors may occur: first, some part of the information necessary to complete the transcript may be omitted. In all such cases, however, the cards are invariably rejected by the tabulating machines, and cannot be counted until the proper corrections have been made; second, the record punched on the card may be inconsistent, as for instance, a young person less than 10 years of age may be recorded as a carpenter. Such incorrect transcripts, however, appear in the tabulations and will then, as a matter of course, be eliminated; third, the card may be so punched that the error may be said to be consistent; for example, a person's age may be 29 years instead of 25 years. Mr. Hunt, Chief of the Population Division, reports as the result of the tests and checks which have been made, that the percentage of this class of error is entirely immaterial.

The number of cards which can be passed through the machine in a day's work of seven hours depends on the number of readings which have to be taken from the dials, which, of course, depends upon the size of the unit of area for which the reading is taken. At the commencement, the daily average number of cards passed through the machine for each worker, with an average of five readings copied off, was 3,404. At the end of July

the average number for each worker, with an average number of nine daily readings, was 7,000. Taking the ten most expert operators in July, the daily averages were 7,879, 8,723, 9,008, and 9,388. In the Vital Statistics Division, the highest daily average for four months was as follows:

January,	12,405,	with	16	readings.
February,	11,912,	"	13	"
March,	12,021,	"	19	"
April,	12,655,	"	18	"

With these figures may be compared those for transcribing census data on cards and compiling by assorting these cards, as was done in preparing the statistics of the insane, deaf and blind. The average number of individual records copied in script per day per clerk was 164. For the last week it was 252. These records contain all the data on the population schedule and also the special data of the class. In assorting these cards about 1,750 per day would be distributed by one clerk and the readings taken.

The conclusion is that the data on population schedules and schedules of deaths can be copied from 25 to 50 per cent more rapidly by punching than by transcribing, and that with punched cards and the electric counting machine, the usual tables can be compiled from 4 to 8 times more rapidly than by assorting the written cards. The relative accuracy of the results of the two methods is about the same.

The saving in time and clerical labor effected by the use of punched cards and the electric counting and assorting machine depends on the number and complexity of the different tables compiled, and on the number of individual records. For the work of the 11th census the saving thus effected is estimated as being at least half a million of dollars. It also depends on the adjustment of the assorting boxes to produce the most convenient classification for succeeding compilations while a given form of table is being compiled on the dials, and the statistician who uses this system must not only plan the forms of the tables, but the order in which they are to be compiled, and the scheme of work of the dials and sorting boxes for each table to produce the most economical results.

In addition to the machines above described, Mr. Hollerith has devised several other ingenious adaptations of electrical counting for statistical work. One of these, which promises to be of much use, is what he calls an integrating device, by which a series of values, as of individual farms, or of crops, indicated by punching holes in a card, for each farm or item are summed up on the dials of the counting machine as the cards are passed through it.

All these mechanical methods of compiling and computing will be more important in a permanent census bureau which is now badly needed in this country, than they are under the present system where they are placed in the hands of a large number of people who must learn how to use them, and are discharged about the time they have done so.

"Our true policy on the silver question." By Edward T. Peters, Washington, D. C.

[ABSTRACT.]

The superior simplicity of a single monetary standard may be readily conceded, and so also may the superiority of gold over silver in respect to compactness and portability. But bimetallists contend that the civilized world cannot pass over from a condition of things in which both the metals were freely used as money to one in which silver shall be used only as the material for subsidiary coinage, without producing an enormous contraction in its metallic currency and thereby augmenting the values of the various monetary units to the great derangement of trade and the serious injury of all debtors, including debtor nations and debtor municipalities. The important thing in a monetary unit which is to serve as a standard of value for deferred payments is uniformity of value; uniformity of weight, fineness, or component material being of importance for the purpose named only so far as it may contribute to uniformity in the more essential particular. And if uniformity of component material is to be secured by banishing from use, save for the very limited purpose of subsidiary coinage, a metal which has heretofore furnished fully one-half of the world's metallic currency, it, in the opinion of bimetallists, not only would not contribute to that uniformity of value which we have just seen to be the prime desideratum, but would necessarily be subversive of it.

If bimetallists are right as to their facts, this conclusion follows from a principle upon which political economists are agreed, namely, the principle that, other things remaining the same, a change in the amount of currency relatively to the amount of business to be done with it necessarily involves a change in its unit value, decrease of amount causing increase of unit value, and *vice versa*.

Many of the present advocates of a single gold standard write as if they were unacquainted with this established principle of economics, but it was not wholly overlooked or disregarded by those with whom the movement in behalf of gold monometallism originated; for that movement, in its inception, was no doubt largely inspired by the idea that there was danger of an undue expansion of the metallic currency as a result of a greatly increased production of the precious metals, and that, in view of the increasing number of devices for economizing the use of money, gold alone, with silver as a material for subsidiary coinage and, perhaps, for the standard money of certain backward nations, including those of the Orient, would suffice to maintain something like the old relation between the supply of money and the amount of business to be transacted through its aid. It is submitted that this view, however honestly entertained by those who were thoughtful enough to give the matter their attention, made a wholly inadequate allowance for the growing monetary requirements to arise from the increase of population and the still greater increase of business, as

civilized settlement, with its industrial and commercial activities, extends over the vast areas of virgin soil offered to human occupation in the two Americas, Australasia, Africa and parts of Asia.

Believing, then, that injurious changes in the relations between the supply of money and the business demand for it and, consequently, in the values of those monetary units by which pecuniary obligations are measured, would have been best avoided by adhering to the use of both gold and silver as the materials for metallic money, bimetallists are naturally of the opinion that, if there were inconveniences connected with the commercial fluctuations of the two metals, the use of diverse coinage ratios in different countries, or the use of one metal here and the other there as the principal monetary standard, a remedy should, if possible, have been found in some measure consistent with the retention of both metals in full monetary use. Such a measure they see in a general international agreement upon some uniform coinage ratio between gold and silver, coinage at such ratio to be unrestricted for each metal, and the coins of either metal to be a full legal tender in satisfaction of pecuniary claims.

Under such an arrangement the monetary demand for the precious metals would invariably be concentrated upon either one which might fall below the relative value assigned to it in the coinage ratio; and the monetary demand is so large that this concentration of it upon the momentarily cheaper metal would suffice to restore its value, the tendency being towards equilibrium between demand and supply at the value established in the legal ratio.[1] It is, of course, conceivable that such changes might occur in the conditions under which the two money metals are respectively produced as to require a change of ratio, or even an entire change in the monetary system of the civilized world; but under any circumstances which have hitherto had a precedent in the history of their use as money, the worst that could happen as a result of changes in relative cost of production without a corresponding change of ratio would be to cause the working of certain mines of the one metal which with a different ratio would be found too poor to pay expenses and the closing or leaving unopened of certain mines of the other which with a different ratio would be worked. For let it be borne in mind that, if there is not naturally any fixed relation between the cost of producing gold and that of producing silver, neither is there, at a given time, any uniformity in the cost of production of either one or the other of those metals except in the scientific sense of the phrase. This makes "cost of production" to mean the cost of producing that portion of the needed supply which is produced under the least advantageous circumstances; and in view of the magnitude of the monetary demand for the precious metals it may pretty safely be predicted that the production of each would adjust itself broadly to a cost corre-

[1] In the paper of which this is an abstract it was shown in some detail that, if this concentration of demand upon the relatively cheaper metal were continued, the increased supply required would only be obtained by working poorer mines, and that its "cost of production," as that phrase is understood by the economist, would thus be increased, necessitating an increase in its market value.

sponding to the ratio fixed upon by general international agreement, say $15\frac{1}{2}$ to 1; and this, too, without any great shrinkage on the one side or expansion on the other.

But while bimetallism as an international policy would be safe and practicable if the necessary international agreement could be secured, free coinage of silver for the United States alone could only result in placing us on an exclusive silver basis; and this, should the movement abroad towards gold monometallism continue, would mean the basis of an indefinitely depreciating metal. With silver coinage still suspended in the Latin Union, and with Austria-Hungary, Russia and some minor nations going, or making obvious preparations to go, over to the single gold standard, we may well ask ourselves whether we, as a people, shall go on coining silver in as large quantities as at present, to say nothing of increasing the quantity under a provision for free coinage, or whether we shall not rather seek other and more prudent means of guarding against the contraction of our currency than that of loading ourselves down with a metal which the rest of the civilized world is combining to make a drug on our hands.

Our first step, however, ought to be to make one earnest effort to secure the international coöperation necessary to make bimetallism safe for us. It is true that we have heretofore made ineffectual efforts in that direction, but there is one step which from the first was obviously of great importance as a condition of obtaining the coöperation desired, and which we have never taken, namely that of declaring our readiness to adopt the coinage ratio of 15.5 to 1, the only ratio upon which any progress has been made towards an international agreement. It is true that such a change of ratio would either reduce the number of grains of silver, or increase the number of grains of gold, in the standard dollar by a little over three per cent.; but if we thereby secured international coöperation in the establishment of free coinage, or even in the general establishment of some such system as that under which we are now operating, the increased demand for silver thus brought about might be expected to increase the value of that metal to a degree which, as regards the effect produced upon the intrinsic value of our standard silver dollar, would very much more than make up for the loss of 12·6 grains in its weight. To object, then, to a reduction in its weight, with this object in view, as an impairment of the obligation of contracts, would be to "strain at a gnat and swallow a camel." The nations of the Latin Union, and other nations having a smaller ratio than ours, may be excused if they attach no value to our coöperation as long as we coin upon a ratio over three per cent higher than their own, since, if a general resumption of free coinage had the effect upon the value of silver anticipated by bimetallists, no sooner would their mints be generally re-opened to that metal than it would be found deserting our mints for theirs and leaving us, as we were for many years prior to the war, theoretically upon a bimetallic basis, but practically using no silver except a very limited amount of fractional coin. The silver bill reported from the Senate Committee on Finance during the last Congress

contained a provision to enable the President to enter into an international arrangement as to the ratio. If this were revived as an independent measure, it might, perhaps, be adopted, especially as it is one to which the advocates of free-coinage could make no reasonable objection, since in no case can they expect to enact into law during the present administration a measure providing for free coinage in the United States without foreign coöperation. The ratio of sixteen to one would no doubt be preferable either to $15\frac{1}{2}$ or to our present clumsy ratio of $15\frac{88}{100}$, and an effort to obtain its adoption might be worth the making; but if the acceptance of $15\frac{1}{2}$ would enable us to secure an international agreement, it ought to be promptly accepted.

There are special circumstances which tend to make the present a favorable time for such an effort as has just been suggested. Our abundant crops, taken in connection with the scarcity prevailing in most European countries, will check any tendency to the exportation of gold from our shores, or even enable us to import it from Europe, and thus compel a halt on the part of nations that are contemplating the exchange of a silver for a gold basis; while the impending danger of war, and a consideration of the financial exigencies which war would bring with it, must also exert a powerful influence in the same direction. Under such conditions, those nations which have a double standard or a single standard of silver should be disposed to welcome a plan which would save them from the necessity of staking their immediate financial future on the slender chances of their being able to obtain an increased proportion of the world's limited gold supply.

THE NECESSITY FOR STATE SUPERVISION OF RAILWAY EXTENSION. By B. W. SNOW, U. S. Dep't of Agriculture, Washington, D. C.

[ABSTRACT.]

AMERICANS naturally take pride in the development of transportation facilities in this country which has marked that period of our national life elapsing since the close of the civil war. This development has been almost entirely along the line of railway building, canal traffic and steam service upon our interior rivers having been relegated to positions of comparative unimportance in the passenger and freight movement of our internal commerce. During the quarter of a century that elapsed between the close of the war and 1890, we added 133,000 miles to our railway system, increasing it nearly five fold at a cost for building and equipment of probably $8,000,000,000. At the beginning of the period no road spanned the continent; now the choice of four routes is offered our people in the journey from ocean to ocean, and our ambitious northern neighbor offers another entirely within her own territory. A map of our country shows a

web of ways that is puzzling, and nowhere is there a district of magnitude whose solitudes are not awakened by the shrill whistle of the locomotive. In the older settled states a citizen can scarcely pass a day out of hearing of this bugle blast of progress. Our railways have become not only the arteries but the veins of trade through which the blood of commerce circulates in obedience to the heart beats of capital. Their links of steel have bound firmly the sections of our common country and removed the greatest source of danger to national life, the danger of breaking apart from mere territorial expansion. New York and San Francisco can touch elbows to-day with greater ease than Philadelphia could consult with Boston or Richmond when the Colonies united their fortunes. Our territory, covering 3,000,000 square miles, is now more compact, more accessible, than was the area comprised within the limits of the original colonies. The danger of breaking to pieces from our own weight has vanished with the advance of the locomotive and telegraph.

In our present position there is much that justifies pride. The record of 167,000 miles of road in operation, nearly one-half of all operated in the world, representing an invested capital of $10,000,000,000 and an annual revenue above operating expenses of $350,000,000 or more than one-half of the ordinary revenues of the government, is one not approached in any other country, indeed hardly in all others together. Such gigantic combinations of capital, brain and energy are without parallel in the world's history.

The rapid extension of the system which has marked the decade still continues. In four years past we have added 31,000 miles, or as much as the total mileage when the war began in 1861. Conditions are now arising, now confronting us which were not foreseen in the earlier days, were only dimly recognized a few years ago, and their gravity is perhaps hardly appreciated even now. The gravest of these conditions is the ultimate relation of the railway to the state. In the formation of our government human wisdom could not foresee the tremendous forces of civilization which were so soon to regulate and accelerate the progress of human affairs. A Gulliver has been introduced into the kingdom of Lilliput.

One prominent reason for weakness in any attempt to settle the railway problem in the interest of the people is the fact that the roads have been chartered as private corporations. The doctrine of the sacredness of a charter on the ground that it is a contract between the state and the corporation which the legislature cannot alter without the consent of the corporation, so ably expounded by Chief Justice Marshall in the Dartmouth College case in 1819, has been pushed to extreme length by the growth of railway corporations, a species then unknown. In almost all the states of the Union, and this is especially true of the older and more important ones, legislatures have reserved no right of supervision, gradually restricting their own power of control and enlarging the sphere of the corporation until the state is practically powerless. It is too evident that the individual states have nursed giants which they can no longer control, and the solution of the problem must be left to the general government, or to corporations

themselves, to be worked out by combinations and consolidations in their own interests without regard to the rights of the people. The question of which it shall be, state ownership, or stringent governmental control, must, however, be left for solution to the statesmen of the period when it can no longer be put off. It is a weakness of democracy to view with alarm, to gravely consider, to temporize, compromise and delay action until the hour of the final crisis is reached. So it will be with the railway problem.

There is one phase of the question, however, which is now ripe for settlement, and with its proper step many of the difficulties in the way of the final adjustment will disappear.

It has been the rule in most states that legislatures have legislated so as to make railroad building easy, a few individuals being allowed to incorporate themselves and go ahead, acting entirely upon their individual judgment and without particular regard to the rights and advantages of the public. As a general thing the only check has been opposition from corporations already established whose territory was to be invaded or whose interests might suffer, and the general welfare of the body public, if defended at all, is defended through this greed or fear. The fact that the public at large is vitally interested in every mile of road laid, in every dollar of money spent, has been overlooked. This ease with which corporations can be chartered has naturally resulted in the building of lines which were not demanded, and upon which the traffic could not be expected to pay a return upon the money invested. The money used in such construction has been taken from the floating capital of the country and transformed into fixed capital, permanently invested and returning no profit. In a partial sense this becomes dead capital, and to that extent active wealth of the country is lost. If a road be built which instead of paying a dividend runs behind each year, and the case is not one of supposition, our business capital is just that much impaired. In 1886 more than one-half of the capital stock of our companies paid no dividend, and upon ten per cent of their bonded indebtedness no interest was paid. All this, however, must be made up in some other way, and here the interest of the public in railway extension becomes apparent. The loss must be made good by higher returns upon productive property, transportation charges are made high enough to cover it, and every man who rides a mile or ships a pound is taxed to make up this deficiency. The public must not only support the productive but the non-productive property as well.

The lack of efficient control of railway extension in the interest of the public leads to another abuse which is even more costly, in the building of speculative and parallel lines for the purpose of selling out to the original line. This has been done successfully in many cases, notably the West Shore Road which parallels the New York Central from New York to Buffalo, and the Nickel Plate which in like manner parallels the Lake Shore from Buffalo to Chicago. In cases similar to these the old lines buy up the new, and the traffic which one might have handled cheaply is forced to pay the doubled expenses of both systems. One road, of course,

can handle a given traffic more cheaply than can two, and the capital necessary to expend in enlarging a road already operated, in order that it may handle increased traffic, will be less than that necessary to establish a new route. For every such speculative venture the public is called upon to pay. Another case very similar, and in which the shipper likewise pays the bill, is where a number of different lines traverse the same country to the same objective point. All are not needed, and the traffic which they divide between them, either by pools and combinations or in the ordinary course of business, must pay dividends upon their aggregate investment, instead of the investment actually needed to handle the business.

Competition between railways can be of little value in regulating rates. The aphorism of George Stephenson that where combination is possible competition is impossible grows truer every day. It is easier and more profitable for corporations to pool their issues and divide their profits than to enter into competition in the ordinary sense of the word. In the nature of things a railway is a monopoly, and two in the same field have usually proven a worse. The idea upon which the legislatures of New York and other states have acted, that with the privilege of railway construction open to all the possibility of monopoly would be averted, is fallacious. The immense capital required to construct a road prevents the building of any large number, and the size and permanency of the investment after it is made makes its operators cautious about fighting rivals when by agreement all can live and fatten off the public.

Those who patronize the railroads pay for every mistake in construction and management, for every speculative investment, for every rival bought off or silenced by a division of profits, for unnecessary employés and swollen pay rolls, and the point has been reached where the interest of the public in railway extension must be considered. If state legislatures cannot effectually supervise such construction, limiting it to such as is demanded by the public good, then the general government should assume control thus far. The sinking of national wealth in unproductive roads, and taxation of business life to make good the loss must be prevented.

THE MUCK SOILS OF THE FLORIDA PENINSULA. By Prof. H. W. WILEY, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE paper describes the character and extent of the muck soils of the Florida peninsula; it also shows what portion of these has already been reclaimed and the plows which are preferred for reclaiming the soil area of rich muck, south of the Okeechobee lake. Maps and diagrams illustrate the paper. The character of the crops produced is also described and the possibilities of future agricultural resources discussed.

THE SOUTHERN OLD FIELDS. By W J McGEE, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

THROUGHOUT the Coastal plain of southern United States abandoned fields abound. When these fields are low or gently undulating they are quickly clothed with pines or with other vegetation, chiefly arborescent; but when hilly and high, as is the case commonly in Mississippi and occasionally in other parts of the region, and ravines are deepened gullies invade the hill slopes and uplands until in some cases the entire soil is washed away and the formerly verdure-clothed surface is transformed into a glaring sand waste; and in the meantime the "bottom lands," once the most fertile of cotton fields, are clogged with the sand swept from the hills until they, too, are utterly ruined for agriculture. In many parts of the Coastal plain this modern surface erosion is limited only; but elsewhere it is of appalling extent. Thus, extensive observations in Mississippi indicate that the commonwealth loses more each year in the destruction of her soil than she gains from all other sources combined.

The reason for this modern acceleration of erosion is not far to seek, and suggests a means for staying the destruction: Within a few years past, geologists have studied systematically the forms as well as the materials of the land and have come to correlate the details of land configuration with the altitude of the land above the sea (or baselevel), with climatal conditions, with the condition of vegetation, etc. Thus it has been determined that an area standing high above baselevel for a considerable period assumes a rugose configuration. It has been determined, too, that there is a configuration characteristic of the prairie and another configuration characteristic of the woodland, the latter being the more rugose; so that the geologist trained in this line of investigation discriminates at a glance the lands cleared of forests by human agency from those naturally grass covered. Now the configuration of much of Mississippi and of many other portions of southern United States is strongly rugose, indicating considerable altitude above baselevel, and also naturally forest covered; and the surface slopes are too strong to stand the action of the storms and the streams when the forest covering is removed. It is true that during the palmy days of the plantations the fields were not eroded chiefly because of the constant use of concentric cultivation, hillside ditches, "balks," and other protective devices; but, when the fields were abandoned, the waters gathered on the hillsides, ran down the slopes and quickly destroyed the surface. In many cases the destruction has gone so far that to check it would cost far more than the value of the lands; but when not too far advanced it may cheaply be checked by the planting of Bermuda grass on the steep slopes and black locust about the heads of the gullies, and by other protective measures.

AGRICULTURE BY IRRIGATION. SOME SOCIAL ECONOMIC POSSIBILITIES. By R. J. HINTON, Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THIS paper was a summarization of irrigation cultivation, its present position in the U. S., the progress made, possible area of arid land reclamation; the area of public land remaining, values and products under irrigation, changes to intensive cultivation to district or community control of water and ownership of works, and illustrative of the tendency to small farm holdings, special production, security of crops, unification of legislation and other economic changes.

WATER MANAGEMENT THE PROBLEM OF THE FUTURE. By Dr. B. E. FERNOW, U. S. Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE solution of the social questions of our time depend mainly on the increase of food supplies and thereby improvement in the prosperity of the greatest number. Such an increase is to be expected from proper water management.

The manner in which water of the atmosphere becomes available by precipitation is most unsuitable for human interests, not only on account of the irregularity in time and quantity, but also by its mechanical action in falling, for in the fall it first compacts the ground, impeding percolation and increasing opportunity for capillary action and rapid evaporation, it loosens rocks and soil, carrying these in its descent down into the river-courses and valleys, thus increasing dangers of high floods and destroying favorable cultural conditions. The value of water in plant productions is discussed.

Water is to be considered as much a resource, to be utilized and managed as such, as the soil or any other gift of nature.

Its main peculiarities are its constancy of supply in general and its inconstancy in local and timely distribution, its instability and furthermore its baneful and destructive tendencies, unless properly managed.

Water management hitherto has mainly concerned itself with getting rid of the water as fast as possible, instead of making it do service during its temporary availability by means of proper soil management, horizontal ditches and reservoirs, irrigation, etc.

Irrigation, which has been confined to arid or subarid regions, is to be applied for plant production in well-watered regions with equal benefit and profit, if combined with proper drainage systems.

Such systems are described; examples of the increase in quantity and value of crops by such systems of combined irrigation and drainage are cited. The irrational lowering of ground water levels by overdrainage is criticised and the proper mechanical treatment of soils discussed.

The relegation of soils to their proper use for production of agricultural crops, meadows, pasture and forest becomes a necessity and especially the latter form of vegetation is pointed out as an important factor in a proper water management. Without forest management no rational water management is possible; a correct distribution and utilization of water is the future problem of agriculture, and an important economic factor. The influence of the forest, especially of the forest floor on the flow of water, is fully discussed and the conclusion drawn that the forest, especially the mountain forest, has a place in political economy of the greatest importance as a regulator of water conditions. A comprehensive organization of water statistics in connection with the agricultural stations and the weather bureau is suggested.

THE NEEDS OF THE AMERICAN FLAX FIBER INDUSTRY. By CHAS. RICHARDS DODGE, Special Agent Fiber Investigations, U. S. Department of Agculture, Washington, D. C.

[ABSTRACT.]

THE trade journals, the importers and many editors of the agricultural press, of a year ago, asserted most positively that flax could not be grown for fiber in the United States, and that the production of seed and fiber in the same plant was an impossibility. The falsity of these assertions has been satisfactorily proven. At this time the farmers need to be shown the difference between poorly grown and prepared flax which is worthless for any purpose, and a grade of flax which a little better practice will give them, and which will be salable for some purpose. The "American practice" of flax culture, to be successful, must be founded on the employment of labor-saving machinery, as far as possible, in all operations. Several inventions for pulling flax have been examined by me in the past year which indicate an early solution of the problem of how to harvest the crop properly at an economical cost. There are two machine threshers which remove the seed without breaking the straw, leaving it straight and untangled. The greatest need, however, is for a class of skilled workers who shall come between the farmers and the manufacturers in the operations of retting and scutching. The latter operation is in no way connected with the work of the farm. One scutching mill in a neighborhood will suffice to prepare the flax grown on a score or more of farms; and the flax from these farms if grown with care will be of even quality. To found an American linen industry there must be three divisions of labor: the growing of the crop by the farmer, the retting and the scutching by the "factor," if we may use this term, and the spinning and weaving by the manufacturer. In the old days of household manufacture all these operations were conducted, on a very small scale it is true, on the farm. But the old days are past and there must be a new order of things. We must even improve upon the present laborious practices in vogue in for-

eign countries, which will give us eventually the "American practice" hinted at above. In any community where farmer, "factor" and manufacturer work together, the flax industry will succeed.

Flax has been grown experimentally, for the U. S. Department of Agriculture, the present year, on fifty or more stations or farms. From the examples of the products already examined it is shown that with care, where mere culture is considered, flax may be grown for fiber over a large territory of the United States. The manufacturing branch of the industry is already established. The operations of retting and scutching therefore are the chief obstacles to success, and our best efforts should be directed to this field of experimental work.

ON A MEASURE OF THE RELIABILITY OF A CENSUS ENUMERATION. By ALEX. S. CHRISTIE, U. S. Coast and Geodetic Survey, Washington, D. C.

[ABSTRACT.]

THE writer suggests that the twelfth census enumeration be taken in a single day, that in a hundred rural and a hundred urban districts the local enumerators be followed in the last hour of the day by a force sufficient to make an absolutely correct enumeration. A comparison of results will afford a basis for estimating the precision of the twelfth enumeration.

A NATIONAL UNIVERSITY, ITS CHARACTER AND PURPOSE. By PROF. LESTER F. WARD, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

THE National University recommended by Washington, Jefferson, Madison, and many later presidents and statesmen is almost certain to be realized in the near future. It is the object of this paper to offer some hints as to what ought to be its character and purpose.

In the first place it should be distinctively *national*, the creature of the American people and devoted to their use and needs. To this end it should be located at the seat of government and should be exclusively the product of the federal government. It should also be in the fullest sense representative, as is the government itself. Its scholarships should be held entirely by Americans, and should be distributed with local uniformity throughout the entire domain of the United States. Recognizing the intellectual homogeneity of the whole American people, it should have representatives from every section of the country. This could probably best be secured by allotting a given number of scholarships to each congressional district on the basis of representation as determined by the census enumeration. Candidates should be admitted by competitive examination held by the faculty or an examining board appointed by the faculty, to be

absolutely free from all political influence. As the intellectual homogeneity of the American people relates to *capacity* and not to attainment, in order to secure such universal representation, the university should be accompanied by a preparatory department, and those who pass the examination for the university should have no advantage over those who pass for the preparatory department, except that if a sufficient number pass for the former, examinations for the latter need not be held. Candidates who enter the preparatory department should be given precedence over those from the same district at the end of that course for admission to the university.

The faculty should be chosen by a commission consisting of the most eminent scholars and scientific men in the country who are entirely above personal and political bias, such, for example, as the National Academy, the board of Regents of the Smithsonian Institution, and other high authorities in the leading departments of learning.

While the institution should be a university in the fullest and widest sense, it should differ from all other universities in one important respect. All universities have their strong chairs, and many rest their reputation on some one leading feature. The leading feature and true reason for being of the national university should be its course of instruction in the science and art of government. This course should differ radically from the usual courses in political economy and political science. These should not be neglected, but, in addition to them and of higher rank should stand, as the basis of university instruction, a thorough and exhaustive course in the practical workings of government itself. Viewing government as the great agency for the transaction of the people's business, every department of government business should be fully taught both in its principles and its practice, so that the graduate from the national university should come forth in full possession not only of all that constitutes true statesmanship, but also of the practical details of each of the many great business operations which the government undertakes and carries on.

The administrative offices of the government should be filled as soon as possible from graduates of the university, so that at length the civil service force of the United States should consist exclusively of persons who have had a thorough training in the theory and practice of government.

THE SCIENCE AND ART OF GOVERNMENT. By Prof. LESTER F. WARD, U. S. Geological Survey, Washington, D. C.

[ABSTRACT.]

GOVERNMENT should be looked upon as the business agency of the nation, and the science and art of government are the science and art of conducting this business agency. The various branches of administration have arisen through pressure from without. Everything that the people have demanded to be done with sufficient unanimity and persistence

has been eventually undertaken by the government. One bureau after another has been created by law, placed in charge of proper officers, and conducted to the best of the latter's ability. Most bureaus have grown and expanded in their scope and usefulness. Many have been several times reorganized and the service perfected.

Although the various systems of administrative operation have been largely empirical, devised by men who had little preliminary preparation for the work, improved through the growth and demands of the service, and brought to perfection by thoughtful study of the needs of the public in each individual case, still the whole rests on a rational basis and constitutes a great system of government. The general laws and principles underlying this system constitute a science,— the science of government. The carrying out of these laws and principles is the art of government, and although, as in the case of almost all the practical arts, it was empirically developed, there is no reason to doubt that it will be as greatly improved and perfected by its reduction to a science and its enlightened prosecution as such, as all the other great industrial arts have been since science has been applied to them.

Among the most promising sources of advantage in the scientific method is the comparative study of government operations. While from a very broad point of view all government is the same, when viewed at all in detail, the greatest individual differences are found. Much of this diversity grows out of the natural differences in the conditions of nations, but fully as much is due to the differences in the methods adopted to accomplish the same purpose. Amid all these varying methods there must be great differences in their efficiency. Some are coarse and clumsy while others are precise and refined. There are all the grades that exist in the manifold mechanical devices of the other arts, those which are best being always those which have most thoroughly utilized natural forces, including the social forces.

The scientific study of government would make the comparative study of methods a leading feature with a view to the recommendation of those which under all circumstances are the very best. This is only one out of any required number of illustrations that might be given of the superiority of the scientific method in government.

In the science of political economy the subject of government operations is destined to occupy an increasingly prominent place. It is safe to say that no chair of political economy in any institution of learning has ever taught or attempted to teach the practical workings of public administration — the way in which the business of the nation is conducted. It is impossible to teach this branch of political economy without the means of a direct examination of the different systems of government business as they are conducted by their respective bureaus. Each great system, such as those of finance, land, patents, etc., etc., would require a course of lectures with repeated visits to the department, inspection of records, books, papers, merchandise, etc. This would require a legal right to prosecute the study in this only practicable way. Nothing short of a na-

tional institution, created and authorized by law to teach the science and art of government could successfully carry out this scheme of education. As a safeguard to our institutions, not less than as a means of national progress and enlightenment, no other educational scheme is equal to it in importance.

THE LOCUST OR GRASSHOPPER OUTLOOK. By Prof. C. V. RILEY, U. S. Entomologist, Washington, D. C.

[ABSTRACT.]

DURING the present summer, and especially during the past six weeks, the papers have contained numerous reports concerning serious grasshopper ravages in various parts of the country, in some cases the reports being quite sensational and well calculated to create apprehension as to the safety of our crops and as to the possibility of serious locust devastation this fall or next year. A few words, indicating the exact state of the case and summarizing the investigations made, may be of service in giving our farmers the true condition of things. While, from the investigations made a year ago of the reports of locust injury, it did not seem probable that there could be very much foundation for the reports of the present year, I deemed it quite desirable to endeavor to ascertain the facts as fully as possible. Accordingly, Prof. Lawrence Bruner was instructed to examine fully the regions in the northwestern states where the injuries were reported, and he has visited eastern Colorado, south and north Dakota, western Minnesota and portions of Montana and Wyoming. Prof. Herbert Osborn was instructed to visit the western parts of Kansas and investigate the southwestern portion of the state, examining all localities from which any reports of injury could be obtained. Profs. F. W. Snow and E. A. Popenoe, on behalf of the state authorities in Kansas, thoroughly examined the section of country in southeast Colorado, passing over northern Kansas, and thus connecting the territory covered by Professors Bruner and Osborn, so that it may be stated that the plains region from northern Minnesota west to Montana and south to the Arkansas river, has been pretty thoroughly examined.

Mr. Nathan Banks was instructed to visit south Texas and New Mexico to inquire into the reports of injury in those sections.

It may be stated in brief that the depredations in eastern and southeastern Colorado have been due to the exceptional multiplication of the Long-winged Locust (*Dissosteira longipennis*). This species always occurs in that section, and some of the first insects which I collected in Colorado on my first visit in 1867 were of this species, and are now in the National Collection. It has not before been reported in such numbers, and its increase furnishes another illustration of the fact that we never know when a species that has hitherto been looked upon as harmless may become seriously injurious to agriculture. During the latter part of July millions of pupæ and full-grown larvæ of this species were found ranging over large

areas of eastern and southeastern Colorado, moving in vast bodies all the way from Akron to the Arkansas river to the south. The insects moved in a body in various directions, choosing, as Professor Bruner reports, the roads for their line of march rather than the prairies. Normally this species frequents partially bare hill slopes and plains where the grasses are scant, and Professor Bruner's view of the matter is that the past few years have been favorable to its excessive multiplication, but that during the present year the exceptionally heavy rains which have occurred in that region have caused an unusually abundant growth of grasses and other vegetation so that the locusts have been compelled to move in search of more open country and have frequented the roads, upon which they congregated and which they followed in vast bodies. He found, in going some distance away from the roadways, where the vegetation was at all rank, that but few insects were found. This species, in size and length of wing, much more closely resembles the migratory and destructive species of Europe and some other countries than the Rocky Mountain Locust (*Caloptenus spretus*) and there seems to be no particular reason why, at times, it should not become destructive and fly in vast swarms from one locality to another. So far as past experience justifies calculation, however, it will not do so, and I think there is little reason to fear any continued or widespread injury from this species.

The locusts found farther north have consisted of several species, most of which are known as sedentary, *i. e.*, not ordinarily migratory. One of them, however, viz., the Pellucid Locust (*Camnula pellucida*) is the species that has already done much damage in California and is one of the Pacific migratory forms. Commencing at Idaho it has been gradually working eastward and is now found in portions of Montana, North Dakota, Wyoming and western Nebraska. The gradual eastward spread and increase of this species deserves attention, but so far as the reports go, it has nowhere been sufficiently numerous to justify alarm. The true Rocky Mountain Locust (*Caloptenus spretus*), the species which we most have to fear was found in considerable numbers in North Dakota and Minnesota, in some counties proving quite destructive, but owing to the vigorous measures which have been adopted especially in Minnesota by the state authorities, chiefly under the direction of Prof. Otto Lugger of the Minnesota Experiment Station, the insects have been largely destroyed, and there is little probability that they will spread extensively from the localities in which they now occur. The destructive species most commonly found in southwest Kansas was the Differential Locust (*Caloptenus differentialis*). It has devastated the Alfalfa fields in the irrigated territory along the Arkansas river for a distance of some fifty miles. This is a widespread species east of the Rocky Mountains, occurring all over the country, and it is one of the species which acquires the power of extended flight only in very dry seasons and under certain favorable conditions. Ordinarily the female is too heavy-bodied and short winged to become migratory. There is no fear of widespread injury from this species. The accounts from southwest Texas have been very greatly exaggerated, and little injury could

be found by the agent sent there. The species were also those indigenous to the region and not of migratory forms that had come from other parts. The reports from Ohio and from some of the other eastern states, though not investigated particularly, need not concern us, because they are known to be based upon the undue multiplication of some of the indigenous eastern species which never acquire the destructive powers of the western migratory forms.

On the whole, therefore, it is safe to conclude that while there are several localities where locusts have been more or less destructive, and required attention, there is no cause for widespread alarm and no reason to believe that any general injury will result in 1892. It will, however, be desirable to gather all the data possible as to the regions where eggs will be thickly laid, and especially to get further data from Manitoba and British North America.

ENERGY AS A FACTOR IN RURAL ECONOMY. By Prof. MANLY MILES, Lansing, Mich.

[ABSTRACT.]

THE rapid development of science and its numerous applications in the industrial arts are leading to a general recognition of its importance as a factor in the material and intellectual progress of the age. The aid of science is now invoked in every department of human activity and, judging from what has already been accomplished, we cannot set any limits to its useful applications in the industries.

While the general outlook encourages optimistic views in regard to the present and prospective advantages that may be realized from the applications of science, we should not overlook the shadows involved in its progress, which seriously interfere with its own advancement and increase the difficulties attending original investigations relating to many industrial problems.

The scope and extended range of modern science that necessitates a subdivision of its lines of research into numerous branches, each of which requires a life time of diligent study for its mastery, are serious obstacles in the investigation of a certain class of problems that can only be solved by contributions from the entire circle of the sciences.

Professor Huxley has sounded a note of warning that should be heeded, especially by those who are engaged in conducting experiments for the advancement of agricultural science.

In his retiring address as President of the Royal Society he said: "Of late years it has struck me with constantly increasing force that those who have toiled for the advancement of science are in a fair way of being overwhelmed by the realization of their wishes.

"We are in the case of Tarpeia who opened the gates of the Roman citadel to the Sabines and was crushed under the weight of the reward bestowed upon her.

"It has become impossible for any man to keep pace with the progress of the whole of any important branch of science. If he were to attempt to do so, his mental faculties would be crushed by the multitude of journals and voluminous monographs which a too fertile press casts upon him. This was not the case in my young days. A diligent reader might then keep fairly informed of all that was going on without demoralizing his faculties by the accumulation of unassimilated information. It looks as if the scientific, like other revolutions, meant to devour its own children; as if the growth of science tended to overwhelm its votaries; as if the man of science of the future were condemned to diminish into a narrower and narrower specialist as time goes on.

"I am happy to say that I do not think any such catastrophe a necessary consequence of the growth of science; but I do think it is a tendency to be feared and an evil to be most carefully provided against.

"The man who works away at one corner of nature, shutting his eyes to all the rest, diminishes his chances of seeing what is to be seen in that corner; for, as I hardly need remind my present hearers, that which the investigator perceives depends much more on that which lies behind his sense-organs than on the object in front of them.

"It appears to me that the only defence against this tendency to the degeneration of scientific workers lies in the organization and extension of scientific education in such a manner as to secure breadth of culture without superficiality; and, on the other hand, depth and precision of knowledge without narrowness."

From the exceeding complexity of many of the problems in agricultural science, and the number of factors that require consideration in attempts to solve them, there is especial need of guarding against the dangers arising from the exclusive prosecution of special lines of research, which are so forcibly stated by Professor Huxley with reference to the general advancement of science.

In almost every problem in agriculture the complex phenomena of life in its various forms and manifestations are directly concerned, which cannot be expressed or formulated in chemical terms, from the self-evident truth that the part cannot contain the whole.

The significance and interdependent relations of the biological factors are unavoidably obscured by the exclusive consideration of specific details which, with the advance of knowledge, may prove to be but incidents in the manifestations of general laws. The solution of these protean problems can only be secured by abstract researches to determine the relations of the several factors to those general laws of which they are the expression.

The principles of science that are admitted to be of general application are the only safe guides in developing an improved and rational system of agriculture, while the purely empirical lines of research that aim to discover specific rules of practice and thus gain immediate practical results, retard the march of progress by the delusive importance assigned to non-essential details. The truth of these statements is illustrated by the re-

markable progress of the physical sciences in the past quarter of a century, and the rapid development of the industrial arts through the recognition and applications of the principle of the conservation of energy, which Faraday looked upon as "the highest law in physical science which our faculties permit us to perceive;" and Huxley refers to it in connection with evolution as "the greatest of all the generalizations of science."

The principle of the conservation of energy, which is now generally admitted to be a prime factor in nature's operations, has not received adequate attention in agricultural science. It is true that in general terms it has been incidentally referred to as a factor in biology, more particularly with reference to mechanical work, but the dominance of purely chemical considerations has prevented its real significance in all organic processes from being fully recognized. More than twenty-five years ago Dr. Wm. B. Carpenter pointed out to physiologists the "distinction between the *dynamical* and the *mechanical* conditions; the former supplying the power which does the work, whilst the latter affords the *instrumental means* through which that power operates." The material conditions have, however, continued to receive a predominant, and almost exclusive, share of attention, and the manifestations of energy in the processes of vegetable and animal nutrition have practically been ignored. In the application of science to agriculture, and especially in planning and conducting experiments, the transformations of matter have been looked upon as the sole factors requiring attention, and a simplicity in organic processes has been assumed that is not warranted by our present knowledge of the conditions that have a decided influence on the nutrition and well-being of plants and animals. An approximate quantitative estimate of the expenditure of energy in certain processes involved in growing a field crop will serve to illustrate its importance in biological science and farm economy, and a preliminary review of some of the salient points in the economy of plants will simplify the problem we have to deal with.

A growing crop, in common with other living organisms, requires certain conditions of environment for the healthy and vigorous exercise of its vital activities, among which may be enumerated as essential,—a suitable temperature, a certain supply of moisture, and a sufficient food supply; and to these must be added soil conditions which promote an extended root development and distribution.

Plants differ as to the temperature required for active growth, but there is for each a minimum below which growth ceases,—a maximum above which life is destroyed, and between these an optimum temperature which is most favorable for the activity of the processes of nutrition. The temperature of the atmosphere, which is an incident of seasons, need not be noticed here, but it may be remarked that not being controllable it is of less practical importance than soil temperatures which depend on conditions that to some extent may be controlled.

Plants obtain their supplies of water from the diffused moisture of the soil, retained by capillary attraction. In fertile soils this capillary water is kept in constant circulation by the drafts made upon it by growing

plants, and by evaporation from the surface soil, and an equilibrium is thus maintained in the distribution of soluble soil constituents, and the processes of soil metabolism.

To say nothing of other important considerations, it is evident that soil conditions, favorable for the extended distribution of the roots of plants, are necessary to enable them to obtain their needed supplies of water from the comparatively limited amount present in the soil. As the water evaporated from the surface soil is replaced from below by capillary attraction, its influence on soil metabolism, and the transportation of soluble soil constituents towards the surface strata, should receive attention as a factor in the economy of plant growth that is closely related to that presented by the water absorbed by the roots of plants and exhaled by their leaves.

In the nutrition and growth of plants an expenditure of energy is evidently required in the work involved in a number of distinct but correlated processes, the most important of which are: constructive metabolism, or the building of organic substance: the exhalation of water by the leaves; the evaporation of water from the surface soil, and the warming of the soil to provide optimum conditions of temperature.

The energy expended in the work of constructive metabolism is stored up as potential energy, which re-appears as heat when the plant is burned or subjected to any of the processes of decomposition.

The mechanical force exhibited by growing plants is a phase of the constructive processes that has often been noticed, as in the experiment by President Clark with a squash which raised a weight of 4120 pounds; or as observed by myself, the sprouts from the roots of a tree pushing their way through an asphalt pavement.

These obvious manifestations of energy in constructive metabolism are, however, so familiar that they require but a passing notice, and we will proceed to consider the much larger expenditures of energy involved in vaporizing the water exhaled by the leaves of plants, and evaporated from the surface soil, as these incidental processes, as they might be termed, are quite as significant factors in plant growth as the direct work of building organic substance, to which the attention of physiologists is more particularly directed. In field experiments the results obtained with manures must largely depend on the expenditure of energy, under the prescribed conditions, in the work of exhalation and evaporation.

Experiments at Rothamsted, England, and on the continent by Hellriegel, on the exhalation of water by a variety of farm crops, including wheat, oats, pease, beans, etc., show that about 300 pounds of water is exhaled by the leaves, for each pound of dry organic substance formed by the plants.

It was estimated by Lawes and Gilbert that the average annual exhalation from the wheat grown on several of the experimental plots at Rothamsted was at the rate of 1,680,000 pounds of water per acre, or the equivalent of 7.4 inches of rainfall, and on the same basis the exhalation from a crop of corn of sixty bushels per acre would be equivalent to about 8.5 inches of rainfall.

So far as the expenditure of energy is concerned it matters not whether water is changed to vapor in the process of exhalation by the crops, or in evaporation from the soil, and the same standard of measurement will therefore be applicable in both cases. Energy, as you all know, is measured in heat units, and work is expressed in foot-pounds, but for convenience of illustration we will make use of another standard adopted by engineers which, although not as definite, is sufficiently accurate for our purpose.

From experimental data it has been found that under favorable conditions, one pound of coal will evaporate from 6.60 to 8.66 pounds of water from an initial temperature of 32° F., according to the quality of the coal used, and if we assume that one pound of coal will evaporate 8.5 pounds of water, our standard will be above what is realized in ordinary steam-engines.

The energy required to vaporize the water exhaled by one acre of corn, with a yield as above estimated, would then be represented by the heat produced by burning 226,500 pounds of coal, or over 113 tons. This may however be expressed in another form that will be readily understood.

We are told that a good condensing engine of large size, supplied with good boilers, consumes two pounds of coal per horse power per hour, and the work involved in the process of exhalation from an acre of corn would, therefore, be equivalent to the work of more than twenty-five horses day and night, without cessation, for six months.

With a sufficient rainfall to supply the requirements of a crop, the amount of water evaporated from the soil will vary, within certain comparatively narrow limits, with the amount and distribution of the rainfall, the capacity of the soil for heat, and the atmospheric conditions that influence evaporation, as temperature, humidity, and the character of the prevailing winds.

From the best evidence I can obtain, which I need not tax your patience to discuss in detail, it appears safe to estimate the average soil evaporation in the Northern states, at approximately twice the amount exhaled by a growing crop of fair luxuriance. Of an annual rainfall of thirty-two inches, or over, fairly distributed, we may then assume with apparent good reason, that about sixteen inches is disposed of by evaporation from a fertile well-drained soil, and about eight inches by exhalation from a growing crop, or, an aggregate of twenty-four inches is removed in the form of vapor, involving an expenditure of energy representing the heat produced by burning 320 tons of coal per acre, or, the work of seventy-three horses day and night for six months.

If to this is added the energy expended in constructive metabolism, and in warming the soil, the sum would represent the normal demands for energy in growing the crop of one acre.

This enormous expenditure of energy appears to be quite as essential to the well being of the crop as the supply of food constituents to which attention has been exclusively directed, and any conditions that tend to materially increase or diminish it, must be looked upon as injurious.

From this standpoint the principle of the conservation of energy furnishes the most satisfactory data for discussing the philosophy of farm drainage.

On undrained, retentive soils, the rain that falls in excess of the normal requirements of the crop and soil metabolism, must be removed by evaporation, and this calls for a very considerable expenditure of energy, that on drained land might be made available in useful work, to say nothing of the influence of this method of removing surplus water on the physical and biological conditions of the soil.

For each inch of surplus rainfall removed from the soil by evaporation, the energy expended would be represented by 26,600 pounds of coal per acre.

With an annual rainfall of forty inches, which is not unusual in the middle states, and is considerably exceeded in some localities, there would be sixteen inches of water in excess of the normal demands of an ordinary farm crop, and to remove this by evaporation would require the equivalent of about 213 tons of coal per acre, representing the work of forty-eight horses day and night for six months.

The removal of this surplus water, by drainage, would obviate the necessity for this enormous expenditure of energy, besides other incidental advantages of importance which we need not notice here.

In the economy of animals the manifestations of the law of the conservation of energy are quite as striking and significant. The potential energy of their food is the sole source of the energy expended in work, and in the processes of nutrition and growth.

Animals have been looked upon as machines for converting the vegetable products of the farm into animal products of greater value, and this, in the light of the law of the conservation of energy, may be interpreted as the conversion of the potential energy of field crops into the useful work of an animal machine. Considered as machines for the manufacture of definite products, their efficiency must depend upon the work performed for a given amount of energy in their food.

An ordinary steam engine formerly converted less than one-tenth of the potential energy of the fuel consumed into useful work, and the attention of engineers has been directed to improvements in construction, to secure greater economy and efficiency in the work performed, by a more complete utilization of the potential energy of the coal, or other fuel used.

The remarkable industrial development of the past few years, resulting in a material reduction of the cost of production and transportation, is largely owing to improvements in the steam engine, which have been brought about by more intelligent applications of the principle of the conservation of energy.

There are good reasons for the belief that the animal machine works with greater economy than the steam engine even in its improved form, but according to the most favorable estimates but a small proportion of the potential energy of foods is utilized in useful work, and there is a broad margin for improvement, even in what we call our improved breeds, to secure a more efficient expenditure of energy.

The problem of paramount interest in animal husbandry is essentially the same the mechanical engineer has been dealing with in his efforts to improve the steam engine.

It is simply to obtain the largest net returns in useful work from the potential energy of the food consumed.

It is evident that improvements in the animal machine itself must be the leading object to receive attention, and the breeders of pure stock must recognize this principle in their efforts for improvement.

The form and proportions in which the chemical constituents of food are provided are of far less importance than the inherited capacity and capabilities of the animal machine to utilize and economize energy in the work involved in the manufacture of animal products.

When speaking of foods we should bear in mind the fact that there is but a limited demand for the so-called nutritive constituents, aside from their agency in the transformations of energy involved in the metabolism of the system.

But a small proportion of the chemical constituents of foods is stored up in the body, even during the period of growth when the demands for new materials in constructive metabolism are most active, while an abundant supply of energy in an available form must be provided as an essential condition of the manifestations of life.

It must not, on the other hand, be assumed that the potential energy of foods may be considered as a reliable index of their physiological value. Biological processes are exceedingly complex, and in calling attention to energy as a dominant factor in vital activities, we do not lose sight of other important considerations which cannot here be noticed.

The protean transformations of energy are constantly carried on in all of the metabolic tissues, and that which is expended in building organic substance in animals, as in plants, is stored up in the form of potential energy as an essential condition of its constitution, and it is again liberated in the form of heat in the correlated processes of destructive metabolism which are taking place without cessation in the work performed in every operation of the system.

Dr. Foster tells us that what is really meant by the phrase "living substance, is not a thing, or body, of a particular chemical composition, but matter undergoing a series of changes." These metabolic changes are brought about, in the main, at the expense of energy, and they represent, in fact, successive transformations of energy from the active to the potential form, and a final reconversion to heat, which leaves the body in various ways.

The animal machine is, in effect, a heat-engine that is constantly being worn out by the work performed, and as constantly repaired by its own processes of constructive metabolism, and the heat leaving the body may be considered as representing the energy that has been used in internal work and finally liberated through the agency of destructive metabolism.

From what is now known in regard to animal physics it will be safe to assume that from four-fifths to five-sixths of the potential energy of the

food consumed by working animals is expended in vaporizing the water thrown off by the lungs and skin, and in the internal work performed by the metabolic tissues, and that the latter leaves the body as animal heat, a very large proportion of which is the result of muscular and glandular metabolism.

The work performed in twenty-four hours, by the heart alone, of a man weighing 150 pounds, is estimated at 75,000 kilogram-metres, an expenditure of energy sufficient to raise his own weight to a height of 3600 feet, and the work performed by the other internal organs, and in vaporizing the water thrown off by exhalation and perspiration is quite as significant.

Another important fact should not be overlooked. In the reconstructive processes that are carried on without intermission in the animal machine, a supply of energy, as we have seen, must be constantly provided to replace that which is thrown off from the system in the form of heat, or expended in external work, but new materials are not required to replace all of the disintegrated constituents of the tissues, as there is a rearrangement to a certain extent, in the processes of repair, of the elements of which they are composed. This is especially the case with muscle, which constitutes so large a proportion of the proteid substance of the body. The work performed by muscle is not at the expense of its nitrogenous substance, and its energy is to a great extent, if not exclusively, derived from the carbo-hydrate elements of the food. The demands of the proteid substance of muscle for nitrogen are therefore limited, and the available supplies of energy in the various elements of the food, determine the efficient activity of the animal machinery.

Energy as a factor in animal physics seems to be overlooked in the application of the popular theory of nutritive ratios. There is a wide difference in the potential energy of feeding rations that have been formulated for the same specific purpose, with practically the same nutritive ratio.

On the same page of a popular agricultural paper I find two rations for milk production, the one having a ratio of 1 to 5 and the other of 1 to 5.1, but there is a difference in potential energy in the two rations equivalent to over 2,411,000 kilogram-metres of work, or one and one-quarter horse power in the day's rations.

Two other rations for milk production with nutritive ratios of 1 to 5 and 1 to 5.1, the difference in potential energy would be represented by 3,112,000 kilogram-metres, or 1.6 horse power for the day's feed.

There are likewise rations with exactly the same nutritive ratio (1 to 5), prescribed for Jersey cows giving milk, in which the difference in potential energy is equivalent to 1,123,600 kilogram-metres, or more than one-half of a horse power for the day.

There are also rations for horses, with ratios of 1 to 6 and 1 to 6.4, which have a difference in energy of 2,834,600 kilogram-metres, or the equivalent of over one and one-fourth horse power per day.

It is unnecessary to cite further instances of the apparent fallacy in rations that have been formulated in accordance with a theory that ignores the significance of energy in animal nutrition.

The facts already presented must be sufficient to show that the law of the conservation of energy should be recognized as an important factor in the economy of both plants and animals, and that it should receive due attention in planning and conducting experiments for the promotion of agricultural science, and in interpreting their results.

THE WORLD'S COLUMBIAN EXPOSITION. By ALEX. D. ANDERSON, Special Commissioner World's Columbian Exposition, New York, N. Y.

[ABSTRACT.]

As you are aware Article one of the constitution of "The American Association for the Advancement of Science" provides that "The objects of the Association are by periodical and migratory meetings to provide intercourse between those who are cultivating science in different parts of America, to give a stronger and more general impulse, and more systematic direction to scientific research, and to procure for the labors of scientific men increased facilities and a wider usefulness."

In harmony with this declaration of purposes the act creating the World's Columbian Exposition is entitled: "An act to provide for celebrating the Four hundredth anniversary of the discovery of America by Christopher Columbus by holding an international exhibition of arts, industries, manufactures, and the products of the soil, mine and sea, in the city of Chicago in the state of Illinois."

In further definition of the objects of the exposition the general regulations have provided the following departments:

A. Agriculture, Forest Products, Forestry, Machinery and Appliances.
B. Viticulture, Horticulture, Floriculture.
C. Live Stock: Domestic and Wild Animals.
D. Fish, Fisheries, Fish Products and Apparatus for Fishing.
E. Mines, Mining, and Metallurgy.
F. Machinery.
G. Transportation: Railways, Vessels, Vehicles.
H. Manufactures.
J. Electricity.
K. Fine Arts: Pictorial, Plastic and Decorative.
L. Liberal Arts: Education, Engineering, Public Works, Architecture, Music and the Drama.
M. Ethnology, Archæology, Progress of Labor and Invention, Isolated and Collective Exhibits.

In brief the two associations are symphatic in their fundamental objects, and are for the promotion and advancement of science, arts and industries of both America and the world. You will, therefore, doubtless be interested in a brief statement of facts relating to the plans, purposes, and progress of the Exposition.

In my opinion the most noticeable features of the preliminary work of the exposition is the unprecedented interest displayed by foreign nations. Never before in the history of a great historical and industrial enterprise has the outside world responded with such promptitude and marked unanimity.

Of course there is a reason for this enthusiasm. It means that the event to be commemorated is of world-wide importance and interest, far surpassing the centenary of a single nation, as for instance the Exposition of 1876. It is in honor of the discovery of a New World, and four hundred years of a new era, and a new civilization. What is this New World, who people it, how is it governed, who own it, what has it contributed to wealth, science, art, and the progress of civilization? We are all familiar with the statistics of the United States on these subjects, but the United States is but one of the nineteen sister republics of the New World which Columbus discovered, and the answer therefore requires a grouping together of the statistics of the various nations of the three Americas.

The total land area of all America is over 15,000,000 square miles.

This immense territory is controlled partly by independent American republics, and partly by European colonies. In North America, exclusive of Mexico, the United States controls one-half and Great Britain the other half. To be more explicit the area of the United States and Alaska is, in round numbers, 3,600,000 square miles, while Great Britain has in her Canadian and other North American possessions 3,400,000 square miles.

Of American republics there are two in North America, five in Central America, ten in South America and two in the West Indies.

Of European Colonies on the continent there is one in North America, one in Central America and three in South America. Of the forty principal West India Islands, Great Britain controls nineteen, France five, Holland six, Denmark three, and Sweden one.

The total population of these various republics and colonies is, in round numbers, 125,000,000 souls.

But still more significant are the facts relating to the material development, progress and wealth of the New World, which illustrate what America has to exhibit in 1893, and why her several nations are making such elaborate preparations for the coming event. She has already constructed 200,000 miles of railways as against 170,000 miles of the rest of the world. She has during the past four hundred years produced $6,200,000,000 in silver, as against $1,180,000,000 of the rest of the world. During the past fifty years her total gold product was $5,950,000,000 in value, while that of of the outside world was but $1,290,000,000.

Her public debt is $2,500,000,000, or only one-tenth that of the whole world.

Her estimated wealth I am unable to find in complete form but that of one of her republics, the United States, is now estimated to be about $62,500,000,000.

The grain crop of this single republic for the year 1891 is estimated at about 3,500,000,000 bushels.

These are but illustrations of the material wonders of the new world which Columbus discovered, but they are sufficient to show why the American republics and colonies are so intensely in earnest in preparing for the coming exposition, and why the nations of the old world are also responding with such marked unanimity. I dwell particularly upon the international features of the Exposition for the reason that its brilliant success in this respect has been somewhat overlooked by the press and public, and the misleading term "Chicago Fair" appears too frequently in conspicuous headlines.

The following nations have already officially accepted:

Europe:—Great Britain, Turkey, Russia, France, Spain, Greece, Germany, Denmark.

Asia and Africa:—China, Persia, Japan, Siam, Egypt.

Australasia:—Australia.

American Republics:—Mexico, Honduras, Chili, Uruguay, Hayti, San Domingo, Guatemala, Salvador, Peru, Venezuela, Ecuador, Nicaragua, Costa Rica, Columbia, Brazil, Argentina.

American Colonies on Continent and in West Indies under European Domination:

Spanish:—Cuba, Porto Rico.

British:—Jamaica, Honduras, Trinidad,

Dutch:—Guiana, Curacoa, St. Martins, Buen Ayre, Aruba, St. Martins, St. Euatatius, Saba.

As will be observed seventeen American republics have already accepted and the remaining two will soon do so. Of the various states of the United States twenty-nine have already provided appropriations, and all others will. I venture the prediction that every commercial nation of the world will be an active participant.

In brief it will be an international exposition in the broadest and fullest sense.

Its quality will be fully equal to its magnitude, for, as you will observe from the classification which I have already mentioned, science, art and education will have a conspicuous place in the various departments.

Nothing will do more to help make it a success worthy of the New World which Columbus discovered than the active interest and coöperation of the American Association for the Advancement of Science and I am particularly glad to observe that your coöperation is already assured.

FREE COINAGE; WHY NOT? By EDWARD ATKINSON, Boston, Mass.

[This paper is published in full in the Forum for October.]

THE ARTESIAN WELLS AND UNDERGROUND WATERS OF CENTRAL TEXAS. By R. T. HILL, Austin, Texas.

[This paper will be printed in Reports U. S. Department of Agriculture.]

THE CODE OF INHERITANCE. By RICHARD T. COLBURN, Elizabeth, N. J.

THE ECONOMIC VALUE OF COOKING SCHOOLS IN THE DISTRICT OF COLUMBIA. By LAURA OSBORNE TALBOTT, Washington, D. C.

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(1). NUMERICAL RELATIONS BETWEEN AMOUNT AND VALUE OF UNITED STATES POTATO CROP, AND AMOUNT OF TRANSPORTATIONS. (2) UNITED STATES MERCANTILE MARINE AND DUTY RATES. By HENRY FARQUHAR, Coast Survey Office, Washington, D. C.

[These papers will be printed in a book entitled "Economic and Industrial Delusions."]

(1.) THE ECONOMY SHIFT OF MACHINERY. (2.) IMMIGRATION AS AN ECONOMIC SOCIOLOGIC PROBLEM. By CHARLES S. HILL, Washington, D. C.

(1.) THE ELEVENTH CENSUS AND STATISTICS OF MANUFACTURE. (2.) A PERMANENT CENSUS BUREAU. By GEORGE A. PRIEST, Special Agent Census Office, Washington, D. C.

TABULATION ERRORS OF CENSUS. By M. C. BAKER.

EXECUTIVE PROCEEDINGS.

REPORT OF THE GENERAL SECRETARY.

THE fortieth meeting of the AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE was called to order on Wednesday, August 19, 1891, at 10 o'clock, A. M., in the Lecture Hall of the Columbian University, Washington, D. C., by Professor GEORGE L. GOODALE of Harvard University, the retiring President, who introduced the President of the meeting, Professor ALBERT B. PRESCOTT of the University of Michigan. Professor Prescott acknowledged the honor bestowed upon him and introduced the Honorable EDWIN WILLITS, Assistant Secretary of Agriculture, who in behalf of the Reception Committee made the following address of welcome to the Association:—

It is to be regretted that the distinguished scientist to whom was originally assigned the pleasant duty to welcome you to Washington cannot be here to perform a duty so much more acceptably and more appropriately than myself. But I assure you that his desire to do so in fitting terms could in no degree surpass mine. Washington is not a stranger to the convocations of national assemblages of all kinds, representing a multitude of interests. Scarcely a week passes that does not herald the gathering together here of men or women, or men and women, from the extremes of the land, too full almost for utterance with zeal for their cause, and inspired with its importance. But this is no ordinary convocation, and this month witnesses a gathering heretofore unknown in the history of Washington, and which it will not see again for many years.

Beginning with the American Microscopical Society on the 11th of August, and ending September 1st with the International Congress of Geologists, there will have crossed the stage in procession one after another, sometimes singly and sometimes in groups, nine scientific associations, all of national, and some of international, importance, carrying on their rolls a membership of thousands, and charged with the mission of finding the fundamental truth of almost every fundamental interest of mankind.

Nearly central in this convocation, both in time and importance, is the association which it is my pleasant duty to welcome to-day, the society to which all the others are affiliated, and of which all the others, in a measure, are component parts. The American Association for the Advancement of Science, both by its distinguished membership and by its work,

has won the consideration of the civilized world, and Washington, not to be behind in this consideration, most heartily welcomes you to-day.

Every four years we witness the inauguration of a new Chief Executive. The transfer, or the continuance of power, is done in the presence of hundreds of thousands, with an acclaim that represents the political voice of the country. Two years ago these broad avenues resounded to the tread of a conclave whose plumed helmets, martial step and inspiring music combined to make a spectacle never surpassed upon this continent. Next year will come the surviving hosts of a grand army that brought to a successful issue one of the most memorable contests of modern times.

The scarred veterans will come again to see Washington, that stands in shining beauty to-day because of their prowess and loyalty. Washington will be untrue to herself if she does not give them such a welcome as shall make the cockles of their hearts so merry that the joy shall last in the memory of the last survivor as he crosses the dark river.

We cannot, gentlemen, welcome you as we do the coming of a new ruler, nor as we do the spectacle of a plumed host, nor as we will the soldier, who fought, suffered, bled, and risked his life for the integrity of the Government under which we all live. We cannot welcome you with any such demonstration. We would not if we could. Such a welcome would not be appropriate. Yet our welcome is as sincere.

In closing, Mr. Willits alluded to the scientific side of Washington's social life as shown in the Cosmos Club, the Anthropological Society, the Biological, Chemical, Geographic and Microscopical Societies.

Dr. J. C. Welling, President of the Columbian University, made a brief address in behalf of the authorities of the University and expressed his gratification at the signs of advancing science and that the Association was holding its meeting in the University.

Replying to these addresses of welcome, President Prescott spoke as follows:

In reply to all the hearty words of welcome extended to this body, I desire to express — and would that I could more fully express — the thanks of this entire Association to all those who have joined in inviting us to hold this meeting here. The invitation last year in Indianapolis and your manifold welcome to-day have made our hearts at home, here where so much of the work of our membership is done. The Association is at home in America wherever its migratory meetings may convene, but in Washington at this time it finds the home of its home made happy with the greeting you have given.

According to the records of the meetings it would appear that the Association has not convened here since 1854. But in all these thirty-seven years the several sections of this body have done work here. And the life of this organization has been going on in this district with more and more of activity and strength as the sciences have been called again and again into the service of the government.

Not a few of the best scientific observations put on record before this

body have been made on this ground and by the forces of exploration having direction under the government.

In each one of the sections this acknowledgment is to be made. Section A has been enriched by the mathematicians and astronomers of the naval service and the Coast Survey. In Section B the length units of light have been brought to the measurement of distances for the American people.

Section C looks to the chemical divisions of the Department of Agriculture and the Geological survey for method and for impulse. Section D knows well the engineers of the Army and Navy. In Section E here, with her vigorous child, the Geological Society, it is always the right of the Geological Survey to bring in the best of the papers. In Section F there are civilians, it is true, but they could not spare the botanists and entomologists of the United States' service. The Bureau of Ethnology must be to Section H what the Census Bureau is to Section I.

Indeed, there is no lack of interest for us all in the place of this fortieth meeting. It is time that the Association should come here, so as to look into its affairs with its Washington fellows and see what is going on. For example, at the last meeting it had come about, all unintentionally, that fifty per cent of the vice presidents were Washington men. So it was thought best to come to Washington with all the vice presidents of other residence and see about it. A little while ago there was another noteworthy instance, in fact more than one of the same kind.

Before President Goodale's time there was a period when the presiding officers were subject to an irresistible force of gravitation to this scientific centre. When elected out of Washington they failed to stay out. It happened more than once. Now that we are all here and while we have the men themselves with us, it will be well to inquire how such things came about.

When we have spoken of those who are with us to-day we remember with sadness those who will not be with us again.

We cannot forget, while we are here, the founders of the Association who were founders of scientific endeavors in Washington. This meeting is a pilgrimage to their memory, as we visit their honored working places. Their names are well known in the sad roll of honor. Alexander D. Bache took charge of the Coast Survey in 1834 and held this charge for twenty-four years. His official reports are his monument.

Another charter member of our body, Joseph Henry, the first secretary of the Smithsonian Institution, brought to it his rare maturity of research in 1846 and to it devoted his eminent abilities until his death in 1878. And it is but four years since the loss of Spencer F. Baird, the distinguished naturalist of the Smithsonian. We pay honor to these fathers in science, founders of our body and to others who have wrought out their lives here, men of large service, to whom America rests under a debt of gratitude.

There is no greater need in this land — unless it be the exclusive need

of righteousness itself — than the need of advancement in science. Let this be understood by all, if America is not to fall short in the nurture of manhood, in the reach of mind and in the arts of peace, if she is not to fall short altogether, she must advance in science and must cherish her writers in scientific research.

Science is not fragmentary invention, is not incidental discovery, is not visionary speculation; it is to know and use the truth in that patience and good order which the truth most requires. Specialties of science are not removed from common life. Men of science are but working out the questions which confront the human race and working in common-sense ways. The terms of science are not more narrowly technical than those of the banking office or the printing house.

The language of learning is no other than the advanced speech of the intelligent public. Words and tools there are fashioned and fitted for sundry uses of scholars and artisans, but always for the common benefit of the people at large. To nurture investigation in science is the largest opportunity before the American people. Let research be sustained in the candor and determination of the scientific spirit, single to the establishment of the truth, and the future will be rich with blessing beyond the fancy of the dreamer.

Research, systematic and wisely directed, requires good organization and strong support. the support of many powers. It must have the devotion of able and persistent men. It needs the conference of workers and the dissemination of knowledge in societies like th is. It wants the interest and the confidence of the public. It asks and will always obtain the constant, helpful use of the press. It requires distinct provision in colleges, in the institutions of higher education. It ought to be sustained, expressly by the government, both in the several states and under the United States and sustained on broad and permanent foundations. Still it needs private benefactions. Research is the growth of years. Let it be the demand of all. And wherever in the land the pages of the press make mention of this Association in its annual meetings, let this call find utterance distinctly, the call for the support of research in science.

This Association and its parent and predecessor, the Association of American Geologists and Naturalists, have been going on—in step with the progress of knowledge — for fifty-one years. As research has extended organization has grown. The first meeting following the Association of Geologists and Naturalists was in Philadelphia in 1848. To relieve the general sessions from the delay of executive questions, the Standing Committee was created at Hartford in 1874, and for still further relief the Standing Committee was reorganized as the Council at Cleveland in 1888. Two sections merely were in operation from an early period. Now the eight sections are in operation.

As a further outcome of the division of labor, clubs of special workers and distinct societies of separate sciences have been born from this Association and hold themselves in filial relations to it. Societies of external

origin and convocations of societies, national and international, have been drawn by the attractive benefits of this great annual meeting and have joined with us one after another in the unities of time and place.

In every meeting we of the membership can not feel too deeply the personal responsibility we bear. It is ours to give wise direction to scientific effort. It is ours to bring forth increase for the sum of knowledge. It is ours to invite new writers to the tasks before us all. It is ours to spread wide the fruits of learning. Especially in the Washington meeting we would rejoice in a good harvest of the growth of the year.

Again we thank you for the invitations extended from the city, and we come bringing our quite numerous family with us, all the members of which we present with parental pride. Other relatives by the mother side will arrive with some friends of theirs before we leave the city. We come from the country, so to speak, and we have with us a bevy of agricultural bodies, of different ages, but so strong a family resemblance that some confusion of identity may be expected. The Geological Society of America is not the geological society of the world, but both bodies are on their way to this place. We beg leave to introduce them all, in confidence that they receive the same welcome extended us. But in our thanks for your most generous greeting it is all we do to speak for the body you welcome to-day

Professor PUTNAM, the Permanent Secretary, presented a financial statement for the year ending August 1, 1891, showing the total receipts to have been $7,443.08. There was a balance left after deducting expenditures of the year of $1,040.92. The amount of the research fund is $5,254.27. Of this the association has the right to appropriate the interest to aid research.

Professor WILEY, the General Secretary, announced that the COUNCIL recommended that the sections meet Wednesday, Thursday, Friday and Saturday from 10 to 12 A. M., and from 2 to 5 P. M., which was agreed to.

Professor WILEY stated that the COUNCIL recommended that the amendment to the constitution proposed last year, "that no one who is secretary of a section be eligible to the office of vice-president until one year after his term of office as secretary," do not pass. The report was adopted. He also stated that the COUNCIL had voted adversely on three other proposed amendments. This action was approved by the Association. These rejected amendments provided, respectively, that "no person should be eligible to election to fellowship at the same meeting at which he is elected a member," that "no fellow should be eligible to election to the Council until one year after he has qualified," and "that the annual dues be $5 instead of $3."

Also, that the COUNCIL reported favorably on an amendment providing for "foreign associates," only it struck out the words "foreign associates" and substituted the term "Corresponding Members." The amendment provides for fifty such members, to be designated by the Council from scientists not residing in America. In the discussion Professor

NORTON proposed to insert the word "North" before America, but withdrew his proposition on a statement by Professor PUTNAM that this was the "American" Association and included all America in its scope.

Prof. E. D. COPE said he was opposed to the amendment, as this was a working Association. Corresponding membership in it, he thought, would confer no especial honor.

Dr. GEORGE F. BARKER of Philadelphia spoke earnestly for the amendment. He said he knew that the members of the Association who were corresponding members of the British Association appreciated the honor very highly, and he believed that such membership in this Association would be similarly appreciated. After further discussion the proposed amendment as reported by the Council was adopted.

Professor WILEY reported the names of members elected at the morning meeting of the Council and read an invitation from the Southern Interstate Immigration Bureau to attend the southern exposition at Raleigh, N. C., in October.

Mr. MARCUS BAKER, the Local Secretary, made several announcements giving important information to members.

The General Session then adjourned and the sections met in their respective rooms for organization and in the afternoon the several Vice-Presidents delivered their addresses.

A GENERAL SESSION was held at 8 o'clock in the evening when the Retiring President, Professor GOODALE, delivered the presidential address. [Printed in this volume, page 1.]

After the address the members and associates of the Association attended a reception at the *Arlington Hotel* tendered by the BOARD OF TRADE.

The hours for the reception were from 9 to 11 and for the two hours the handsome reception and banqueting rooms of the Arlington were thronged with people, for the most part from outside of the city, though there was a fair proportion of people well known in the Washington social and scientific world. Several of the rooms were decorated with flowers, and altogether the entertainment was a most delightful midsummer affair. There was a pleasant air of informality and the occasion was improved by the members generally in renewing old friendships and making new ones. In a corner of the large banquet room was set a table on which were great bowls of lemonade and iced punch that proved very popular, for it was a warm evening.

As the guests entered the first of the suite of drawing rooms they were met by Prof. OTIS T. MASON and introduced to the receiving party.

The Marine Band, under the leadership of Mr. Petrola, was stationed in one of the rooms and gave a delightful program of musical selections that added to the pleasure of the evening.

Sooner or later the guests in their promenade around the rooms found

themselves in the banquet room, and when it was learned that there were to be a number of addresses there the people gathered in force around a raised dais that stood against the wall on the north side of the room. President PARKER of the Board of Trade was the first speaker of the evening and afterward acted the part of host in introducing the other speakers. He spoke in his usual graceful and pleasant vein, and his remarks were enthusiastically received. He began by saying that as a business man he naturally felt embarrassed in speaking before a gathering of scientific people who are wont to weigh every word so carefully. He would scarcely have had the courage to address them were it not for the pleasure it gave him to be able to tell them how welcome they all were to the nation's capital. Within the past two years there have been upward of three hundred national and international societies that have held their conventions in this city. All of them have been welcome, but none more so than the Association for the Advancement of Science. Mr. Parker referred at some length to the growth and improvement of the city during the past thirty years and said that if it was true that all roads lead to Rome then surely all avenues of culture should lead to Washington, the capital city of one of the greatest and most prosperous countries on the globe. He closed by introducing Commissioner DOUGLASS.

Mr. DOUGLASS said that five hundred or more men, learned as specialists in almost every direction of scientific thought and performance, cannot be entertained by any community for a week without a permanent benefit to such a community. Association was education. It would be dangerous to resurrect the controversy (if it was settled or buried) between the classics and science. But when he caught a glimmer of what applied science is doing for the world, he could not but think that it was fast distancing its wordy competitor. In a late ride of several thousand miles by rail he felt the immeasurable sense of safety that the chemical section of the scientific world had given in the matter of steel rails, cheapening the steel so as to make it practicable in place of iron. The sense of safety was reinforced at every sharp curve when running at high speed. This was applied science at its best.

But the chemical profession had its troubles as well as successes, and is undoubtedly entitled to deepest sympathy in its prolonged struggle along the line of baking powders. How happy they would be when the perfect powder of the future shall give to every man and woman not less than three score years and ten of healthy, happy life. This would indeed be a royal road to the end of life's journey.

We have, said Mr. Douglass, plenty of fresh water coming through 1,250,000 feet of pipe, and the death rate of Washington is lower than in New York, Philadelphia, Boston, Brooklyn or Baltimore. So you see that while we have a good city to live in it is comparatively a difficult one to die in. All this improvement, municipal and private, is due to the great capital in which every citizen is a partner, though on the limited plan. As convention after convention meets here of the learned, the commercial or

the æsthetic, a renewed incentive is given to Congress and the people of the District to continue the work of improvement. Therefore we are doubly benefited by such an assemblage as this—the pleasure of the meeting and the increasing power of favorable public sentiment.

Secretary FOSTER followed Commissioner Douglass. He said that he had heard Mr. Parker and Mr. Douglass welcome people lots of times, but he really must say he never had heard them do it better or with more earnestness. As for himself, he really did not know what to do when Mr. Parker had told him he was to be called upon for an address. He had sent up to the library for some data about science, but found that all the books on science were out. The only thing left was a complete set of Porter's Census. He would not dare to quote from that, for every town and hamlet in the country had sent in its protest against its share in the work. Still I can say that on the whole the United States is in a pretty prosperous condition. He knew it was fashionable for some scientists and some people here connected with the new party to talk about the poverty of certain classes of people, notably the farmers, and the accumulation of wealth in a few hands. But he made bold to say that the wealth of the country was never as well distributed as it is at present. People talk about farm mortgages, but the value of the corn and wheat crops of this year over those of last would suffice to pay all these off many times over.

We do need, said he, wise legislation and a sound monetary system, but every dollar should be the equal in value to every other dollar. But let me quote a few figures from an unpublished report of Mr. Robert Porter. According to that the assessed wealth of the country in 1890 was twenty-four thousand millions of dollars as against sixteen thousand millions in 1880, while the real value of the resources was sixty-two thousand millions against forty-three thousand millions in 1880. The per capita wealth has increased from $514 in 1860 to $780 in 1870, $870 in 1880 to $1,000 in 1890. We are safe in concluding then that the country is not going to the dogs, but that it is more prosperous than ever before. Let me finish by telling you that no class of people has done more to bring about this prosperity than that represented by your organization.

Short remarks in response were made by Professor PRESCOTT, Professor GOODALE and Professor BREWER.

TUESDAY, AUGUST 20. The Association met in General Session at 10 A. M., President PRESCOTT in the chair.

The LOCAL SECRETARY announced that:—

An invitation was extended the members to visit the Weather Bureau office in the evening between 9 and 10 o'clock and observe the method of receiving, recording and analyzing the weather reports. An invitation was extended to visit the Naval Observatory evenings between 9 and 10 o'clock. Also that arrangements were making to visit the Corcoran Art Gallery and further details of the opening of the gallery were furnished.

He also announced that, by order of PRESIDENT HARRISON, the private grounds of the White House would be thrown open for the entertainment of the members and that the U. S. Marine Band would be in attendance from 5 to 7 o'clock P. M.

The election of new members was announced, and the Association adjourned to meet in Sections.

From 5.30 until 7.30 in the evening the private part of the White House grounds was opened to the members of the Association, who enjoyed a charming concert by the U. S. Marine Band under Director S. Petrola, tendered the visiting scientists by direction of President HARRISON.

The programme was Watson's grand march, "The Queen's Jubilee;" the overture from Rossini's "William Tell," Sousa's "International Congress," concluding with the "Star Spangled Banner, Bucalossi's valse, "Mon Amour;" flute solo by Henry Jaeger, Treschoek's "La Sonambula," selections from Wagner's "Lohengrin," Mitra's march, "Les Voluntaires;" Koelling's grand galop "The Hunting of the Lion and Fyles," and "Hail Columbia."

The concert was throughout a success, and will be remembered as one of the pleasant episodes of the Washington meeting.

FRIDAY, AUGUST 21. The Association met at 10 A. M. in General Session, President PRESCOTT in the chair.

The LOCAL SECRETARY announced that the Corcoran Art Gallery would be open to members wearing badges on Monday from 1 to 4 P. M. and from 8 to 10 P. M.

He read an invitation from the authorities of the National Museum of Hygiene to visit that institution any day between the hours of 9 and 4 o'clock.

Notices of the excursion to be given during the meeting were read, viz.: On Saturday and Sunday to Harpers Ferry, the Valley of Virginia, and the Luray Caverns; and to Old Point Comfort, Norfolk and Virginia Beach.

On Monday to Baltimore and suburbs. On Tuesday to Mount Vernon.

At 8 o'clock in the evening, by invitation of the Council, a lecture, complimentary to the citizens of Washington, was given at the NATIONAL MUSEUM, by Dr. JOHN M. MACFARLANE, of Edinburgh; Subject: *Illustrations of Heredity in Plant Hybrids*, with three parallel lantern demonstrations. By courtesy of the Director, the National Museum was open after the lecture for inspection of the collections.

A meeting of the NOMINATING COMMITTEE was held in the Arlington at 10.30 o'clock.

SATURDAY, AUGUST 22, President PRESCOTT called the morning General Session to order at 10 o'clock.

The GENERAL SECRETARY reported the following recommendations of the COUNCIL:—

That Messrs. S. P. Langley, E. C. Pickering, T. C. Mendenhall, W. R. Warner, G. N. Saegmuller, William Harkness, J. A. Brashear, and Alvan G. Clark be a committee on standards of astronomical and physical units.

Adopted.

That the Committee on Indexing Chemical Literature be continued and Dr. Alfred Tuckerman be added to the Committee.

Adopted.

That the following resolutions reported to the Council for Section D be adopted by the Association.

Agreed to.

"*Whereas*, A knowledge of the strength and physical characteristics of American Timbers, when used in commercial sizes is absolutely essential to scientific designing, and to any economic use of such materials in the arts, and

Whereas, Little or no reliable or definite information on this subject is now obtainable, since no adequate tests and examinations of American Timbers have ever been made.

Therefore, Be it resolved by the American Association for the Advancement of Science, that the elaborate studies and experiments now so auspiciously begun by the Forestry Division of the Agricultural Department of the U. S. Government, has our most hearty approval and moral support.

We recognize in this work one of the most elaborate and valuable series of tests ever undertaken, and we think the benefits are sure to be far reaching not only to botanical science and forest culture, but to engineering and architectural designing, and to the manufacturers and dealers in American woods, in widening the field of the foreign demand. We trust these tests may receive so strong a support that they will be pushed to an early completion so that the results may be made available as soon as practicable."

That the following resolutions reported to the COUNCIL from Section E be adopted.

Agreed to.

"*Whereas*, The Wheeling Development Co. have by their energy and public spirit put down a test well at Wheeling, W. Va., to the great depth of 4500 feet, and

Whereas, The Company have by their President, Hon. N. B. Scott, and Secretary, J. C. Brady, and Board of Directors, donated and dedicated this well to the cause of Science, and

Whereas, Mr. Anton Reyman of the Wheeling Development Co. has guaranteed the funds for drilling the well at least 1000 feet deeper, and

Whereas, This well is the deepest in America, the second in the world and the only dry deep well, and offers a matchless opportunity for scientific investigation, be it

Resolved, That this Association with pleasure recognizes the great value of this unique gift to Science and herewith officially gives testimony of its appreciation, and gratitude to these gentlemen.

Resolved, That a copy of these resolutions duly signed, be forwarded to the Wheeling Development Co., Wheeling, W. Va., J. C. Brady, Secretary."

That the following report of the Committee on Forestry be accepted and the Committee continued.

Agreed to.

REPORT OF THE COMMITTEE ON FORESTRY A. A. A. S. 1891.

The work of the committee on forestry during the past year has been confined to the personal activity of its members, in coöperation with similar committees of other associations. As a result in part of these efforts may be cited the insertion of a section in the law of March 3, 1891, revising the land laws in general, which authorizes the President of the United States to withdraw and reserve from sale or other disposal such public timber lands as he may deem fit.

Under this Act, the President has enlarged the boundaries of the Yellowstone Park. A necessary enlargement of the Yosemite Valley Reservation is anticipated and a number of other reservations in Minnesota, Montana, and Idaho, Colorado, New Mexico, and California, comprising several million acres, will be asked for in a Memorial, prepared for the American Forestry Association, to which your committee is asked to add the weight and influence of the Association.

While the reservation of public timber lands for the purpose of preserving their forest conditions is a wise first step, it will be readily understood that the object of the reservations cannot be attained without adequate protection and administration of the same, for which there exist no proper provisions.

The energies of the friends of forestry reform will, therefore, be bent during the coming legislative session, upon securing the passage of administration laws and to aid in such purposes the continuance of your Committee is respectfully asked.

For the Committee,
B. E. FERNOW,
Secretary.

Committee:

T. C. MENDENHALL,
B. E. FERNOW,
WM. SAUNDERS,
C. E. BESSEY,
E. W. HILGARD.

The COUNCIL also recommend that the following communication received by the Council from Section F, be agreed to by the Association.

Adopted.

"Copy of resolutions passed by the AUSTRALASIAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE at the meeting held at Christchurch, New Zealand, 1891.

(1) That it is desirable to secure greater uniformity in Biological Nomenclature, especially in the department of Morphology.

(2) That in order to secure such uniformity the following steps be taken: (*a*) The appointment of an international committee to define terms of general importance, *e. g.* terms common to botany and zoology, terms

relating to position, etc. (*b*) The preparation of an authoritative historical glossary of biological terms. (*c*) The systematic record of new terms in the various recording publications.

(3) That copies of these resolutions be transmitted to the British and American Associations and to the Anatomische Gesellschaft."

"The Sectional Committee of Section F reported to the Section, the recommendation that a committee of five from the members of that section be appointed to take the matter into consideration. Upon motion the recommendation was adopted and the chair appointed the following committee: — Professors G. L. Goodale, J. M. Coulter, C. S. Minot, S. H. Gage, and T. Gill."

The COUNCIL also recommends the adoption of the following:

That the A. A. A. S. respectfully submits for the consideration of the Secretary of Agriculture that the future of successful and more productive agriculture depends very largely upon a rational *water management*, meaning thereby not only the use of water for irrigation in the arid and subarid regions, but the rational distribution and use, in the humid regions of available water supplies by means of horizontal ditches and irrigation systems combined with proper mechanical preparation of the soil and with drainage systems, with the object of fully utilizing the water for plant production and providing for the safe and harmless removal of the surplus. The present policy of forest destruction and of allowing our waters to run to waste, not only entails the loss of their beneficial influence upon plant production but permits them to injure crops, to wash the fertile mould from the soil, and even to erase and carry away the soil itself.

It is upon these considerations that the Association respectfully suggests to the Hon. Secretary the desirability of utilizing the Weather Bureau, the various agricultural experiment stations and other forces in forming a systematic service of water statistics and in making a careful survey of the condition of water supplies which may serve as a basis for the application of rational principles of water management.

The recommendation of the COUNCIL was agreed to and the Secretary was instructed to communicate the same to the Honorable Secretary of Agriculture.

The COUNCIL also recommends the adoption of the following resolutions received from Section F, relating to the formation of a NATIONAL ARBORETUM:—

Whereas, The arborescent flora of the United States excels in variety of useful plants any country of the earth under one government;

Whereas, The District of Columbia and the Capital of the Nation are climatically so situated that nearly all the species of the North, South, East and West may be grown there in the open, or with a minimum of protection;

Whereas, The interest in arboriculture and forestry, although growing rapidly, requires an advancement of knowledge, and still more the fostering care of the Government;

Whereas, The Capital is destined to become a centre of learning and instruction to all classes of the people and the accumulation of means of education and opportunities of increasing knowledge here is most desirable;

Therefore, The American Association for the Advancement of Science respectfully submits to the Congress of the United States the propriety of creating an Arboretum in or near the District of Columbia, to be established under the direction of the Department of Agriculture, and asks that a sufficient appropriation be made for such an establishment at once, and further appropriations for its continuance.

These resolutions were adopted and the Secretary was directed to send copies of the same to the proper officers of Congress.

The COUNCIL presents the following communication from Section F, with the recommendation that $100 be appropriated from the Research Fund for the purpose indicated on condition that $400 be raised by a committee to be appointed by the Association:—

To the Council of the A. A. A. S.:—

At the afternoon session of Section F, Saturday, August 22d, a paper was presented setting forth the importance of establishing an American Table at the International Marine Biological Station at Naples, Italy, and calling attention to the fact that Americans, who had obtained permission from various foreign governments to occupy tables supported by them, were not permitted by the director of the station to work there, on the ground that the tables supported by the various governments were intended for citizens of these respective governments, consequently, if Americans desired to pursue investigations at Naples, America would be obliged to support a table for their use.

A committee consisting of Dr. Stiles, Dr. Smith and Dr. Gill, all of Washington, were appointed by the Section on Biology to present the matter to the COUNCIL of the A. A. A. S., and to communicate to the COUNCIL that Section F unanimously and most heartily endorsed a proposition suggested to the Section, *i. e.*, that an American table should be established at Naples in the name and under the patronage of the A. A. A. S., and request the COUNCIL to vote all or part of the necessary $500, and in the latter case to arrange for raising the remainder.

In this connection the Committee begs leave to present the following facts:

The International Marine Station at Naples was established by Dohrn, Huxley, Darwin, Balfour, and others about twenty years ago, but with the two exceptions noted below, it has never received any official recognition or support from any American Scientific Society or Institution.

The station is supported by the rental of tables at $500 per annum; these tables are subscribed for by the various governments and scientific societies of Europe. The approximate distribution of the tables December 31, 1890, was as follows:

Prussia (Government)	3
Saxony "	1
Bavaria "	1
Hamburg	1
Berlin Academy of Science	1
German Empire, (Government)	3
Other kingdoms, etc	3
Total for Germany	13
Italy	8
Austria	3
Russia	3
England (British Association 1, Cambridge 1, Oxford 1)	3
Spain	3
Switzerland	1
Belgium	1
Holland	1
Total	36

Besides the above support of thirteen tables, the German Empire grants $20,000 to the station annually.

Since the station was established, Williams College supported a table for two years; University of Pennsylvania, one year. Prior to January 1, 1891, about eighteen Americans worked at the Naples station; three of these occupied the American tables above, while the remainder occupied tables supported by Germany, Cambridge University or the British Association.

Last year the Director of the station decided to exclude all Americans from further use of the station until America should be willing to support a table.

Maj. Alex. Henry Davis, of Syracuse, N. Y., on learning of the existing state of affairs, kindly offered to support an American table for the year 1891. Three American biologists have already taken advantage of this opportunity to carry on investigations in the world's greatest laboratory.

As already stated, Section F, of the A. A. A. S., unanimously sustains the proposition that an American table should be supported at Naples for the year 1892, and thereafter, if possible, and respectfully submits the proposition to the COUNCIL. Further, the Section on Biology wishes to call particular attention to the arrangement certain European navies have made with the Director of the Naples station. Various officers of the navies are sent to the station to learn the methods of preserving marine animals for scientific investigation. Could not our Navy be induced to support a table at Naples, and to send the officers of the Mediterranean fleet to the station to learn the zoölogical technique? If such a plan were followed, every American navy vessel could shortly be supplied with an officer—the surgeon, for instance—who would be in a position to make use of the rare opportunities afforded him in his long voyage to collect and preserve in a proper manner material for scientific investigation.

Respectfully submitted,

C. W. STILES,

Chairman of Committee of Section F.

It was then voted that $100 be granted, when the remainder of the $500 is raised and a Committee consisting of C. W. Stiles, Theo. P. Smith, T. Gill and B. E. Fernow, was appointed by the President.

The Committee was given executive powers in raising the funds and disposing of the same for the purpose named.

[The amount was raised by the Committee, and the Association paid the $100.—PERMANENT SECRETARY.]

The GENERAL SECRETARY reported that the Council had, upon the recommendation of Section C, granted from the research fund $50 to Dr. EDGAR F. SMITH of the University of Pennsylvania in aid of an investigation now in progress upon the electrolysis of the rare metals.

Also that upon the recommendation of Section B the Council had granted $100 from the research fund to Professors Morley and Rogers in aid of their investigations to determine the coëfficient of expansion of a bar *in vacuo* between 0^0 and 100^0 C.

The GENERAL SECRETARY also reported from the COUNCIL the following preamble and resolution:

Whereas, It is believed that the advancement of science might be greatly stimulated in many directions by judicious and opportune grants of moderate sums of money to investigators of known ability and character;

Therefore resolved, That the Council of the A. A. A. S. appoint a committee consisting of eight members, one from each section of the Association, who shall take such steps as they may deem best to solicit from friends of scientific investigation throughout this country the pledge of sums of money in any amount which shall in the aggregate, constitute "a fund for the endowment of original research," to be under the control of the A. A. A. S.

Resolved, That the members of this committee shall have power to act from the date of the passage of this resolution and that they shall report progress on the third day of the meeting of the A. A. A. S. in 1892.

Mr. J. A. BRASHEAR in supporting the resolution said that he was in favor of establishing a fund to encourage scientific research. He said that so much had been accomplished by those who had been aided by the small fund at the disposal of the Association that he believed the work ought to be carried on on a larger scale. This was done by the British Association, and our own National Academy of Science has funds for this purpose, and he thought that a great democratic body like the American Association ought to have a fund of at least $100,000. He was confident that if the members would make a personal effort in this direction that the money would be forthcoming. For one, he said, he was going to make the experiment. After remarks by several other members, President Prescott added his endorsement and said that he hoped this would start a movement which would result in the collection of this much-needed fund.

Upon motion the President was authorized to appoint a committee of one from each section, Mr. Brashear to be Chairman of the committee.

[This committee was afterwards appointed by the President as follows:—J. A. Brashear, Section A; Francis E. Nipher, B; S. A. Lattimore, C; R. H. Thurston, D; John J. Stevenson, E; C. V. Riley, F; Thomas Wilson, H; Edmund J. James, I.]

The GENERAL SECRETARY stated that on the request of Section A the COUNCIL recommended the appointment of a Committee to secure further data for the determination of the secular and periodic changes in terrestrial latitudes, to consider the question and devise means for conducting a complete investigation of this character.

The recommendation was adopted and the following committee was appointed: T. C. Mendenhall, B. A Gould, T. C. Chamberlin, C. L. Doolittle, R. S. Woodward, F. V. McNair, and G. C. Comstock.

The GENERAL SECRETARY stated that the Council had appointed the following members of the Association as delegates to the International Congress of Geologists which is to meet in Washington during the following week:—The President, the Permanent Secretary, and the Vice Presidents and Secretaries of Sections E and F.

The LOCAL SECRETARY, Mr. Marcus Baker, made a number of announcements; among others, that the Corcoran Gallery would be open for the inspection of the members on Monday afternoon and evening. An invitation had also been received from Mr. Thomas E. Waggaman to visit his gallery Monday morning. Invitations were also received to inspect with Mr. Holmes the ancient Indian quarries at Piney Branch, on Monday afternoon.

The General Session then adjourned until Tuesday evening.

MONDAY, AUGUST 24. The day was given up to excursions and to visits to the various departments of the government.

TUESDAY, AUGUST 25. The afternoon was given up to an excursion to Mount Vernon tendered to the members and associates of the Association by the Scientific Societies of Washington.

At 8 o'clock in the evening the Association was called to order in General Session by President PRESCOTT.

The NOMINATING COMMITTEE presented a list of officers for the meeting of 1892, and by unanimous vote the SECRETARY was instructed to cast the ballot for the nominees. [The list of officers is printed on page xvii.]

The following invitations were read by the GENERAL SECRETARY:

Mayor's Office,
Rochester, N. Y., Aug. 14, 1891.

PROF. F. W. PUTNAM,
SECRETARY A. A. A. S.

It gives me great pleasure as mayor of the city of Rochester and personally as a citizen to join with the other departments of the city government and the educational associations of the city in extending to the American Association for the Advancement of Science a cordial invitation to hold its meeting of 1892 in Rochester, N. Y. We can promise you a hearty welcome and the local conditions of a successful meeting.

W. B. CARROLL, *Mayor.*

City Clerk's Office,
Rochester, N. Y., May 20, 1891.

At a regular meeting of the common council held Tuesday evening, May 19, 1891, the following resolution, offered by Alderman Lewis, was adopted:

Resolved, That the common council extend to "The American Association for the Advancement of Science" a cordial invitation to hold its annual convention in this city during the summer of 1892, and that the use of the City Hall be and it is hereby tendered to said Association for that purpose.

A true copy from the clerk's minutes.

PETER SHERIDAN,
City Clerk.

Department of Public Instruction.
Office of Superintendent of Schools, S. A. ELLIS, *Supt.*
Rochester, N. Y., May 23, 1891.

At a regular session of the Board of Education held May 18, 1891, the following was unanimously adopted:

Resolved, That a hearty invitation be extended by the Board of Education of the City of Rochester to the American Association for the Advancement of Science to hold its forty-first annual meeting in this city in August, 1892; and further,

Resolved, That the free use of the rooms and hall in the Free Academy Building be tendered to the Association and its affiliated societies.

MILTON NOYES,
Clerk pro tem.

Rochester Chamber of Commerce,
Rochester, May 14, 1891.

MY DEAR SIR:

At a regular meeting of the Chamber of Commerce May 11, the inclosed resolution was unanimously adopted.

Very respectfully,
GEORGE MOSS,
Secretary.

Prof. H. L. FAIRCHILD,
University of Rochester.

Resolved, That the Rochester Chamber of Commerce, recognizing the importance and interest to this city which would result from the holding of the forty-first annual meeting of the American Association for the Advancement of Science at Rochester in 1892, hereby extends cordial invitation to the officers and members of that body as well as to its subsidiary and affiliated societies (including the Official Agricultural Chemists, the Chemical Conference, the Entomological Club, the Botanical Club and the Geological Society of America) to accept the hospitalities of this city and the use of the Chamber of Commerce on the occasion of its next year's convention; and that the Secretary forward copies of this resolution to the officers of said Association at the coming meeting in Washington, D. C., to the Rochester Academy of Science and to Prof. H. L. Fairchild of the University of Rochester.

University of Rochester, Rochester, N. Y.
June 16, 1891.

PROF. F. W. PUTNAM,
SECRETARY AMERICAN ASSOCIATION
FOR ADVANCEMENT OF SCIENCE, SALEM, MASS.

DEAR SIR:

The Board of Trustees of the University of Rochester extend a very cordial invitation to your Association to hold their next session in the City of Rochester. The use

of the College Buildings will be placed at your disposal for purposes connected with your sessions.

Very respectfully yours,
THOS. M. WILLIAMS,
Secretary.

University of Rochester, Rochester, N. Y.,
June 12, 1891.

PROF. F. W. PUTNAM,
PERMANENT SECRETARY, A. A. A. S.
SALEM, MASS.

DEAR SIR:

At a meeting of the Faculty of the University of Rochester held this day, the following resolution was unanimously adopted.

"Recognizing the many advantages that would accrue to the educational and scientific interests of Rochester from the presence here of the American Association for the Advancement of Science, and the affiliated Societies, the faculty of the University of Rochester extends to the American Association for the Advancement of Science an urgent invitation to meet in this city in the year 1892. And the members of the Faculty furthermore promise their hearty coöperation in adding to the pleasure, and otherwise securing the success of the meeting."

Yours very truly,
HERMAN LEROY FAIRCHILD,
Secretary of the Faculty.

Rochester Academy of Science,
Rochester, N. Y., March 9, 1891.

PROF. F. W. PUTNAM,
PERMANENT SECRETARY,
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

DEAR SIR:

At a meeting of the Rochester Academy of Science held this date, it was unanimously voted that a hearty invitation be extended to the American Association for the Advancement of Science to hold its annual meeting of 1892 in the city of Rochester.

It was also voted that the various scientific and civic institutions of the city should be asked to join in the invitation.

It gives us great pleasure to transmit to you the invitation as stated above, and to express an earnest hope that the Association may be prevailed upon to hold its forty-first Annual Meeting in this city.

Yours very truly,
H. L. FAIRCHILD,
President,
FRANK C. BAKER,
Secretary.

May 15, 1891.

PROF. H. S. FAIRCHILD,
PRESIDENT OF THE ROCHESTER ACADEMY OF SCIENCE.

At the last monthly meeting of the *Rochester Historical Society* it was upon motion resolved and unanimously carried, that the Society unite with the *Academy of Science* in inviting *The American Association* to meet in this city in 1892.

We leave our invitation in your hands for presentation with that of other Rochester societies, at the August meeting of the Association.

JANE MARSH PARKER,
Corresponding Secretary.

Rochester, N. Y., July 21, 1891.

PROF. H. L. FAIRCHILD,

DEAR SIR:

Will you kindly in behalf of the Rochester Athenæum and Mechanics Institute, extend to the American Association for the Advancement of Science, a cordial invitation to hold its sessions for 1892 in this city.

It would give the members and trustees of this Society great pleasure to assist in any way that they may to make the session pleasant to the members of that Association.

Respectfully yours,

E. R. ANDREWS,

President R. A. and M. I.

Rochestèr, N. Y., June 16, 1891.

PROF. F. W. PUTNAM,

SECRETARY AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,

SALEM, MASS.

DEAR SIR:

The Board of Directors of the Young Men's Christian Association, of the City of Rochester, extend a very cordial invitation to the American Association for the Advancement of Science to hold their next session in the City of Rochester. They also beg to place at your disposal the use of their newly erected Association Building, at the corner of Court and So. St. Paul Sts. We believe that the Building will be admirably adapted for the purposes of your convention, committee meetings, etc.

Very truly yours,

DEAN ALVORD,

Secretary.

The Rochester Business University,

Rochester, N. Y., May 29, 1891.

PROF. F. W. PUTNAM,

SALEM, MASS.:

DEAR SIR:

The people of this city are greatly delighted with the encouragement they have received that the American Association for the Advancement of Science may meet here next year.

Prof. H. L. Fairchild, of the University of Rochester, has suggested to us that our apartments, taken with the rooms of the Young Men's Christian Association, would accommodate your society admirably. We have thirteen rooms, some of them very large, one seating 165, besides some smaller rooms, which would do for committee rooms. The Y. M. C. A. has a convenient suite of class and committee rooms, besides a beautiful Music Hall, seating 1,200. These rooms are all under one roof, provided with a large, fast elevator, and are eligibly located.

Should you find our apartments adapted to the needs of your Association we shall be delighted to have you occupy them, and we have no doubt the Y. M. C. A. will extend you as cordial an invitation to occupy their portion of the building.

Very respectfully yours,

L. L. WILLIAMS.

Camera Club, Rochester, N. Y., June 20, 1891.

PROF. H. L. FAIRCHILD,

CITY.

DEAR SIR:

At a meeting of the Camera Club, May 29th, it was unanimously voted to join the other societies of Rochester in extending an invitation to the American Association

for the Advancement of Science to hold their forty-first annual meeting in this city in 1892.

Yours very truly,

J. L. WILLARD,

Secretary.

At a meeting of the Rochester Dental Society, held June 10, 1891, the following was unanimously adopted:

Resolved, That the Rochester Dental Society join with local and other scientific bodies in extending to the American Association for the Advancement of Science a most cordial invitation to hold its meeting of 1892 in this city.

Resolved, That the Society communicate this action to the American Association through its local representative, Prof. H. L. Fairchild.

CHAS. F. HOWELL,

Secretary.

The following letter relative to the meeting of 1893 was also read:

Madison, Wis., Aug. 12, 1891.

PROF. ALBERT PRESCOTT,

PRESIDENT OF THE A. A. A. S.,

WASHINGTON, D. C.

MY DEAR SIR:

Having been informed that your Society has under consideration the question of the place of meeting outside of Chicago for the year of 1893, I as Mayor of this city, in behalf of the people, extend to your Society, through you, a most hearty and cordial invitation for such meeting in our city.

We have one of the most beautiful cities in the United States, located about 130 miles north of Chicago.

There are now and will doubtless be then special trains with excursion rates running from Chicago to this city.

This is the capital of the State, and in addition to the great natural beauty of the town, we pride ourselves on being a great educational centre.

Hoping you may consider us kindly, and assuring you, if you decide upon Madison as the place of your meeting, we will leave nothing undone to make your stay in our midst pleasant and enjoyable,

I am, very respectfully yours,

WM. H. ROGERS,

Mayor.

For and on behalf of the Business Men's Club, of Madison, I most heartily concur in this invitation.

LUCIUS FAIRCHILD,

President.

The GENERAL SECRETARY stated that the NOMINATING COMMITTEE had voted to recommend the acceptance of the cordial invitations from Rochester to hold the next meeting in that city, and that the time of the first General Session of 1892 be Wednesday, August 17, at 10 A. M.

The recommendations were unanimously agreed to by the Association.

The following amendments to the constitution were proposed:

By the Sectional Committee of Section A, That ARTICLE 33 be amended to read:

Immediately on the organization of a Section, there shall be three fellows elected by ballot, after open nomination, who, with the Vice President and Secretary, and with the Vice President and Secretary of the preceding meeting shall form its Sectional Committee.

By Section F,

ART. 22, line 4, to be amended so as to read: F, Zoölogy; G, Botany.

By Dr. C. P. Hart:

That the following words be added to ART. 29: Not more than two papers by the same author shall be read in any one Section until all other papers which have been accepted shall have been read before the said Section.

[These proposed amendments will be acted upon at the next meeting.]

Mr. MARCUS BAKER, the Local Secretary, made several announcements relative to return tickets, excursions and various other matters of importance to the members.

The PERMANENT SECRETARY gave a summary of the statistics of the meeting. [These appear in his report on a following page.]

The GENERAL SECRETARY read the following resolutions, which were feelingly and earnestly seconded by the gentlemen indicated:

Whereas, The fortieth meeting of the A. A. A. S., now about to close, has been by the concurrent testimony of all participants an eminently successful meeting; and

Whereas, This success has been due to the hearty good will and coöperation and to the zeal, energy and good judgment of various persons and organizations;

Therefore be it resolved by the Association, that its hearty thanks be and are hereby tendered to each and every person and organization that has contributed to its success; and further that while here recording its thanks in general terms the Association desires to place on record an expression of its special thanks:

1. To the Board of Trustees and the President of Columbian University, Dr. James C. Welling, for the free use of the University building which has so well served as a home for the Association during its stay in Washington. (Response by President T. C. Chamberlin.)

2. To the Scientific Societies of Washington which through their joint commission first invited the Association to meet in the National Capital and afterward made every provision for the scientific work, comfort and pleasure of the members, and particularly to Col. Garrick Mallery, President, and Mr. Marcus Baker, Secretary of the joint commission. (Response by Prof. H. T. Eddy.)

3. To the President of the United States and to Col. O. H. Ernst for the reception in the private grounds of the Executive Mansion; to Assistant Secretary of the Navy Soley and to the Marine Band, by whose efforts the pleasure of the reception was greatly enhanced. (Response by Dr. Joseph LeConte.)

4. To the National Museum and its director, Dr. G. Brown Goode, for

the special facilities afforded in the use of the lecture hall and corridors of the Museum both day and evening; to Dr. Frank Baker for his many attentions to members visiting the Zoölogical Park, and to many other government officials for courtesies extended in various ways. (Response by Prof. E. D. Cope.)

5. To the excursion and reception committees whose zeal and unremitting labors for our comfort and recreation have added much to the pleasure of the meeting. Also to the Baltimore & Ohio and Shenandoah Valley Railway Companies for material concessions in connection with the excursion to Luray; to the officers of the steamer Macalester for constant attention during the excursion to Mt. Vernon; to Mr. W. H. Holmes for the arrangement of details of the excursion to aboriginal quarries on Piney Branch; to Prof. C. L. Reese for guiding the excursion to Baltimore, as well as to Mr. F. W. Wood, President, and Colonel Franklin, Superintendent of the American Steel Company; to Captain Carter of the steamer F. C. Latrobe; to his Honor the Mayor of Baltimore; to Mr. A. S. Abell of the *Sun*, General Agnew of the *American*, and to other representatives of the press of Baltimore; to Dr. Henry M. Hurd, Superintendent of the Johns Hopkins Hospital; to Mr. Wm. M. Perot of the Baltimore Sugar Refinery; to the Harbor Board of the city of Baltimore; to Mr. Henry Jones and to many citizens of that city. (Response by Prof. T. H. Norton on the Luray excursion; Prof. F. E. Nipher on the Mt. Vernon excursion; Mr. Frank H. Cushing on the excursion to an aboriginal workshop; Rev. H. C. Hovey on the Baltimore excursion.)

6. To the Women's Anthropological Society of America and the Ladies' Reception Committee growing out of this organization, to whose efforts we are indebted for many acceptable arrangements in the University building, as well as for several receptions to our members; and especially to Mrs. Marianna P. Seaman, Acting Chairman, and Mrs. Anita Newcomb McGee, Secretary of the special reception committee for the Association. (Response by Prof. Joseph Jastrow.)

7. To the Board of Trade and to its President, Col. Myron M. Parker whose courteous efforts to increase the pleasure of our visit to Washington was so thoroughly successful. (Response by J. A. Brashear.)

8. To the Trustees of the Corcoran Gallery of Art and to Mr. Thomas E. Waggaman for the opportunity so courteously extended of visiting their choice collections of works of art. (Response by Constantine Hertzberg.)

9. To the City Post Office and to the Chesapeake and Ohio Telephone Company for facilities granted to the Association. (Response by Prof. J. H. Chapin.)

10. To the Press for the fullness and accuracy of their reports, and the general circulation of the same through the agency of the Associated Press. (Response by Major J. W. Powell.)

11. To the Local Committee; especially the Hon. Edwin Willits, Chairman of the Reception Committee; to Mr. Marcus Baker, Local Secretary; to Richard Rathbun, Chairman of the Committee on Printing; to Mr.

Everett Hayden, Chairman of the Excursion Committee; to Mr. W J McGee of the Committee on Place of Meeting; to Prof. F. W. Clarke of the Committee on Entertainment; and to Mr. Henry Gannett, Chairman of the Committee on Transportation. (Responses by Prof. E. W. Claypole, Mr. Geo. W. Holley, and Prof. F. W. Putnam.)

President PRESCOTT, after expressing his grateful thanks for all that had been done by the Local Committee and the citizens of Washington in aiding the work and the pleasures of the members of the Association as partially expressed in the resolutions, called for a vote upon them and they were unanimously adopted.

The President then made a few remarks, upon the character and success of the meeting, and expressing the hope that all would meet at Rochester declared the fortieth meeting of the Association concluded.

HARVEY W. WILEY,
General Secretary.

REPORT OF THE PERMANENT SECRETARY.

In 1854 the Association held its eighth meeting in Washington, under the presidency of Prof. J. D. Dana, and the records show that only 168 members were in attendance, although the number of members on the list for that year was 1,004; a number that was not again reached until 1879 when there were 1,030 names on the roll. At the recent meeting 653 members were registered, including associates and honorary foreign members. Of these 220 were from the city of Washington and adjoining portions of the District of Columbia, while the total membership of the Association was 1,993 at the opening of the meeting.

The register shows that the members in attendance were from the following places: District of Columbia 220, Ohio 54, New York 75, Pennsylvania 37, Indiana 27, Massachusetts 24, Maryland 19, Michigan 17, Missouri 15, Illinois 13, Iowa 13, Virginia 10, Canada 9, Wisconsin 9, New Jersey 8, Texas 7, Connecticut 7, Alabama 6, North Carolina 6, Louisiana 6, Kentucky 5, Tennessee 5, Nebraska 3, West Virginia 3, Colorado 3, California 3, Mississippi 3, Arkansas 3, Florida 3, New Hampshire 2, Georgia 2, Arizona 2, South Carolina 2, Kansas 2, Minnesota 2, Vermont 1, Rhode Island 1, Delaware 1, North Dakota 1, and Germany 9, Russia 5, England 2, Austria 2, France 2, Bavaria 1, Switzerland 1, Sweden 1, Scotland 1. Total, 653.

Of the 368 members elected since the Indianapolis meeting and during the Washington meeting, 4 have declined membership, 1 was already a member, and 247 have perfected their membership as have 5 who were elected at the Indianapolis meeting; 31 members have paid their arrears and have been restored to the roll, and 3 corresponding members have been elected, making 286 names added to the roll since the Indianapolis volume was published. From the Indianapolis list 31 names have been transferred to the list of deceased members; 28 members and fellows have resigned and 108 have been omitted for arrearages, making a deduction of 167 from the list; 3 have become life members and 59 members have been transferred to the roll of fellows.

The following is a comparative statement of the roll as printed in the Indianapolis volume and in the present volume:

	Indianapolis.	Washington.
Patrons,	3	3
Corresponding members,	0	3
Members,	1,185	1,269
Honorary fellows,	2	2
Fellows,	745	777
	1,935	2,054

The distribution of publications since the last report is as follows:

Memoirs No. 1: sold 4; exchanges 2. Total, 6 copies.

Transactions: sold 1 copy.

Vols. 1–37: delivered to members 66; sold 77; exchanges 61; presented 13; duplicate copies to members 2. Total, 219. Returned by exchanges 7; bought 1.

Vol. 38: delivered to members 74; sold 9; exchanges 2; presented 2; duplicate copy to member 1. Total, 88. Bought 1 copy.

Vol. 39: delivered to members 1,662; sold 26; exchanges 242; presented 4; duplicate copies to members 3. Total, 1,937. Bought 1 copy.

Of the 248 papers brought before the Council, 21, for various reasons, were not read in the sections. Of the 227 placed on the daily programme, 20 were read in Section A, 23 in B, 33 in C, 14 in D, 30 in E, 47 in F, 34 in H, 25 in I. 6 reports were made by committees; 8 addresses were given by the vice presidents, and the president's address and one lecture were given at evening sessions. One paper was read in general session. Meetings were also held by the Botanical Club when 25 papers were read, and 23 papers were read at the meetings of the Entomological Club.

Preceding and following the meeting of the Association, from Aug. 11 to Sept. 1, meetings were held by the following societies: the American Microscopical Society, the Association of American Agricultural Colleges and Experiment Stations, the Association of Official Agricultural Chemists, the Society for the Promotion of Agricultural Science, Conference of American Chemists, Association of Economic Entomologists, the Geological Society of America, and the International Congress of Geologists.

As stated in the following cash account, the balance on hand preceding the Washington meeting was $1,040.92.

The amount of the GENERAL FUND with interest to Aug. 1, 1891, is	$126.03	
The amount of the RESEARCH FUND, as stated in the Indianapolis volume, was	4,861.22	
Interest to Aug. 1, 1892, ...	243.05	
Life membership commutations 1891–2, . . .	150.00	
	$5,254.27	
By votes of the Council at the Washington meeting, there has been paid:		
To Professors Morley and Rogers in aid of their investigations in determining the coëfficient of expansion of a bar in vacuo, etc., . . .	$100.00	
To Prof. Edgar F. Smith in aid of his investigations upon the electrolysis of the rare metals, . .	50.00	
To the Committee on the American Table at Naples,	100.00	
	$250.00	
		$5,004.27

F. W. PUTNAM,
Permanent Secretary A. A. A. S.

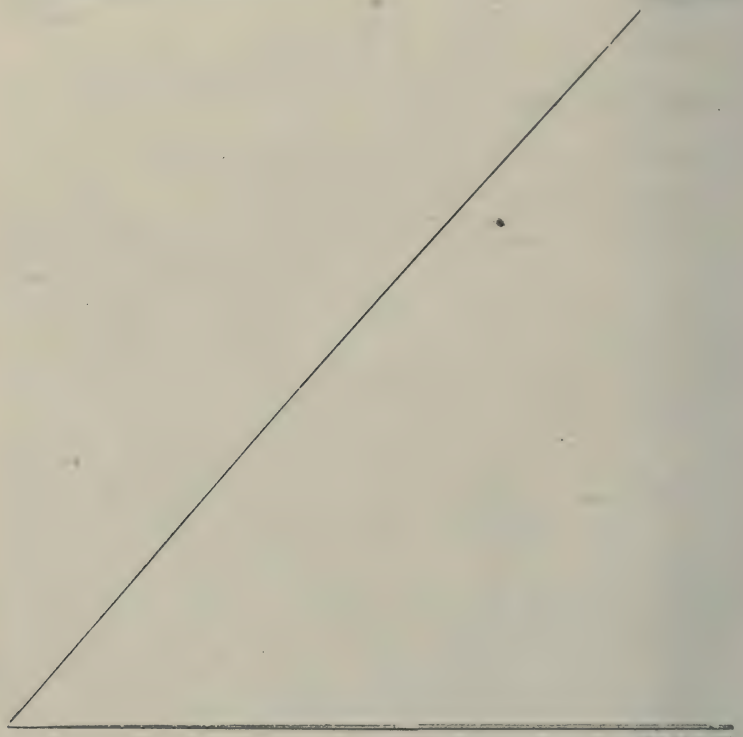
Salem, July 8, 1892.

F. W. PUTNAM, PERMANENT SECRETARY,

Dr. THE AMERICAN ASSOCIATION FOR

1890–91.

To admission fees Washington Meeting	$315 00	
" " previous to Washington Meeting	945 00	
Fellowship fees	138 00	
		$1,398 00
Assessments previous to Indianapolis Meeting	828 00	
" for Indianapolis Meeting	3,741 00	
" for Washington Meeting	522 00	
Associate fees, Indianapolis Meeting	90 00	
		5,181 00
Publications sold	75 82	
Binding	46 05	
Postage and express charges refunded	2 17	
Exchange on checks	1 15	
From unknown sources in 1882	6 00	
		131 19
Life membership commutations		150 00
To balance from last account		582 89



$7,443 08

I have examined the above account and

WASHINGTON, D. C., AUGUST 27, 1891.

IN ACCOUNT WITH
THE ADVANCEMENT OF SCIENCE.

		Cr. 1890-91.
By 2500 copies Proceedings Vol. 39 (597 pages)		
Composition and corrections	$1,106 26	
Illustrations	6 38	
Electrotyping 62 pages	44 15	
Paper, $506.00, and press work, $250.00	756 00	
Paper covers and binding 2400 copies	296 50	
		$2,209 29
Binding 25 copies Vol. 39, half morocco	25 00	
" 75 " " " cloth	37 50	
25 cloth covers	5 00	
Printing wrappers and wrapping 2500 copies	34 50	
3225 extra copies of addresses and reports	156 44	
		258 44
500 copies Constitution and list of members	39 75	
Printing circulars, blanks, cards, etc.	211 42	
Binding back Vols. of Proceedings	8 80	
Insurance	19 00	
Illustrating Vol. 39	10 00	
		288 97
Expenses Indianapolis Meeting	449 91	
" Washington Meeting	18 25	
Express, including distribution Vol. 38	333 44	
Postage, stationery, and P. O. Box rent	276 36	
Telegrams	2 05	
		1,080 01
Engrossing resolutions Indianapolis Meeting	15 00	
Expense Lecture Indianapolis Meeting	5 30	
Subscription to Postal Guide	1 00	
Petty expenses	4 85	
Boxes for transportation	4 55	
Rent of Office	108 00	
Janitor to Aug. 1, 1891	100 00	
		238 70
W. H. Seaman, expense of Committee on Meteorology	10 00	
T. H. Norton, expense of Committee on Chemical terms	19 00	
R. B. Warder, expense of Committee on Sec. C	14 75	
H. W. Wiley, expense as Secretary of Council	33 00	
		76 75
Grant to Professor Morley from Research Fund		250 00
Carried to Life Membership Fund		150 00
Salary of Permanent Secretary to Aug. 1, 1891	1,250 00	
Salary of Assistant Secretary to Aug. 1, 1891	600 00	
		1,850 00
Balance on hand to new account		1,040 92
		$7,443 08

certify that the same is correctly cast and properly vouched.

THOMAS MEEHAN, *Auditor.*

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